
BrainStat

Release 0.3.3

MICA Lab, CNG Lab

Dec 17, 2021

TABLE OF CONTENTS:

1	Developers	3
2	License	5
3	Support	7
	Python Module Index	77
	Index	79

Welcome to BrainStat's documentation!

BrainStat is a toolbox for the statistical analysis and context decoding of neuroimaging data. It implements both univariate and multivariate linear models and interfaces with the BigBrain Atlas, Allen Human Brain Atlas and NImare databases. BrainStat flexibly handles common surface, volume, and parcel level data formats, and provides a series of interactive visualization functions. The toolbox has been implemented in both Python and MATLAB, the two most widely adopted programming languages in the neuroimaging and neuroinformatics communities. It is openly available, and documented [here](#).



DEVELOPERS

- Reinder Vos de Wael - MICA Lab, Montreal Neurological Institute
- Şeyma Bayrak - Max Planck Institute for Human Cognitive and Brain Sciences
- Oualid Benkarim - MICA Lab, Montreal Neurological Institute
- Sara Lariviere - MICA Lab, Montreal Neurological Institute
- Raul Cruces - MICA Lab, Montreal Neurological Institute
- Peer Herholz - Montreal Neurological Institute
- Seok-Jun Hong - Sungkyunkwan University
- Sofie Valk - Max Planck Institute for Human Cognitive and Brain Sciences
- Boris Bernhardt - Montreal Neurological Institute

LICENSE

The BrainStat source code is available under the [BSD \(3-Clause\) license](#).

SUPPORT

If you have problems installing the software or questions about usage and documentation, or something else related to BrainStat, you can post to the [Issues](#) section of our repository.

3.1 Installation Guide

BrainStat is available in Python and MATLAB.

3.1.1 Python installation

BrainStat requires Python 3.7+. Assuming you have the correct version of Python installed and aliased to *python*, you can install BrainStat by running the following

```
python -m pip install brainstat
```

Python Dependencies

If you want to use the meta analysis module, you'll also have to download and install the package pyembree. This package is only available through conda-forge:

```
conda install -c conda-forge pyembree
```

3.1.2 MATLAB installation

This toolbox is compatible with MATLAB versions R2019b and newer.

We recommend installing the toolbox through the Mathworks [FileExchange](#). Simply download the file as a toolbox and open the .mltbx file in MATLAB. Alternatively, you can install the same .mltbx file from our [GitHub Releases](#).

If you don't want to install BrainStat as a MATLAB Toolbox, you can also simply [download](#) the repository and run the following in MATLAB:

```
addpath(genpath('/path/to/BrainStat/brainstat_matlab/'))
```

If you want to load BrainStat every time you start MATLAB, type `edit startup` and append the above line to the end of this file.

MATLAB Dependencies

BrainStat relies on functionality included in the BrainSpace toolbox. Please see the BrainSpace [installation guide](#) for installation instructions.

If you wish to open gifti files (required for data loader function) you will also need to install the [gifti library](#).

3.2 Python Index

3.2.1 Tutorials

Tutorial 01: Linear Models

In this tutorial you will set up your first linear model with BrainStat. To this end, we will first load some sample data from the MICS dataset.

```
from brainstat.datasets import fetch_mask, fetch_template_surface
from brainstat.tutorial.utils import fetch_mics_data

# Load behavioral markers
thickness, demographics = fetch_mics_data()
pial_left, pial_right = fetch_template_surface("fsaverage5", join=False)
pial_combined = fetch_template_surface("fsaverage5", join=True)
mask = fetch_mask("fsaverage5")
```

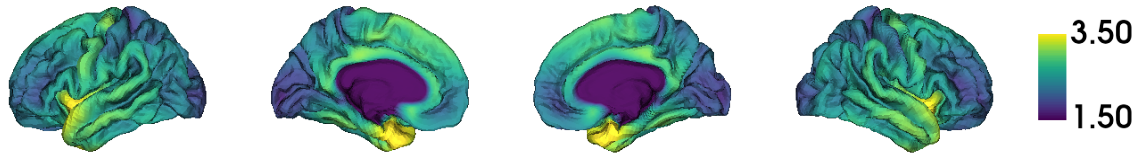
Lets have a look at the cortical thickness data. To do this, we will use the surface plotter included with BrainSpace. As we'll be plotting data onto these hemispheres quite often in this tutorial we'll create a simple function for it and plot mean thickness here.

```
import numpy as np
from brainspace.plotting import plot_hemispheres

def local_plot_hemispheres(values, label_text, color_range, cmap="viridis"):
    # Plot cortical surfaces with values as the data, label_text as
    # the labels, and color_range as the limits of the color bar.
    return plot_hemispheres(
        pial_left,
        pial_right,
        values,
        color_bar=True,
        color_range=color_range,
        label_text=label_text,
        cmap=cmap,
        embed_nb=True,
        size=(1400, 200),
        zoom=1.45,
        nan_color=(0.7, 0.7, 0.7, 1),
        cb_labelTextProperty={"fontSize": 12},
        interactive=False,
    )

local_plot_hemispheres(np.mean(thickness, axis=0), ["Cortical Thickness"], (1.5, 3.5))
```

Cortical Thickness



Out:

```
<IPython.core.display.Image object>
```

Lets also have a look at what's inside the demographics data.

```
print(demographics)
```

Out:

```

SUB_ID  VISIT  AGE_AT_SCAN  SEX
0   031404    1   -0.579678    F
1   04a144    1   -0.812116    M
2   0b78f1    1    0.117636    M
3   0d26b9    1    0.466293    F
4   1988b8    1   -0.114802    M
..     ...    ..     ...    ..
77  f25714    1   -0.231021    F
78  f25714    2    0.117636    F
79  f615a5    1   -0.695897    F
80  feac6b    1   -0.695897    F
81  feac6b    2   -0.347240    F

```

```
[82 rows x 4 columns]
```

Demographics contains four variables: a subject ID, a visit number (some subjects visited multiple times), their age at the time of scanning and their sex. Lets also print some summary statistics.

```

# Print demographics summary.
for i in range(1, 3):
    print(
        (
            f"Visit {i}, N={np.sum(demographics.VISIT==i)}, "
            f"{np.sum(demographics.SEX[demographics.VISIT == i] == 'F')} females, "
            f"mean subject age {np.mean(demographics.AGE_AT_SCAN[demographics.VISIT_
↪== i]):.2f}, "
            f"standard deviation of age: {np.std(demographics.AGE_AT_
↪SCAN[demographics.VISIT==i]):.2f}."
        )
    )

```

Out:

```

Visit 1, N=70, 30 females, mean subject age -0.02, standard deviation of age: 1.02.
Visit 2, N=12, 5 females, mean subject age 0.09, standard deviation of age: 0.84.

```

Next, we will assess whether a subject's age is related to their cortical thickness. To this end we can create a linear model with BrainStat. For our first model, we will only consider the effect of age, i.e. we will disregard the effect of sex and that some subjects visit twice. this end we can create a linear model with BrainStat. First we declare the age variable as a FixedEffect. The FixedEffect class can be created in two ways: either we provide the data with pandas,

as we do here, or we provide a numpy array and a name for the fixed effect. Lets set up the model $Y = \text{intercept} + B1 * \text{age}$. Note that BrainStat includes an intercept by default.

```
from brainstat.stats.terms import FixedEffect

term_age = FixedEffect(demographics.AGE_AT_SCAN)
model = term_age
```

As said before, if your data is not in a pandas DataFrame (e.g. numpy), you'll have to provide the name of the effect as an additional parameter as follows:

```
term_age_2 = FixedEffect(demographics.AGE_AT_SCAN.to_numpy(), "AGE_AT_SCAN")
```

Lets have a look at one of these models. As you can see below, the model is stored in a format closely resembling a pandas DataFrame. Note that an intercept is automatically added to the model. This behavior can be disabled in the FixedEffect call, but we recommend leaving it enabled. We can also access the vectors related to each effect by their name i.e. `model.intercept` and `model.AGE_AT_SCAN` will return the vectors of the intercept and age, respectively.

```
print(model)
```

Out:

```
   intercept  AGE_AT_SCAN
0           1    -0.579678
1           1    -0.812116
2           1     0.117636
3           1     0.466293
4           1    -0.114802
..         ...         ...
77          1    -0.231021
78          1     0.117636
79          1    -0.695897
80          1    -0.695897
81          1    -0.347240

[82 rows x 2 columns]
```

Now, imagine we have some cortical marker (e.g. cortical thickness) for each subject, and we want to evaluate whether this marker is different across the the lifespan. To do this, we can use the model we defined before, and a contrast in observations (here: age). Then we simply initialize an SLM model and fit it to the cortical thickness data.

```
from brainstat.stats.SLM import SLM

contrast_age = demographics.AGE_AT_SCAN
slm_age = SLM(
    model,
    contrast_age,
    surf="fsaverage5",
    mask=mask,
    correction=["fdr", "rft"],
    cluster_threshold=0.01,
)
slm_age.fit(thickness)
```

The resulting model, `slm_age`, will contain the t-statistic map, p-values derived with the requested corrections, and a myriad of other properties (see the API for more details). Lets plot the t-values and p-values on the surface. We'll do this a few times throughout the tutorial so lets define a function to do this.

```

def plot_slm_results(slm, plot_peak=False, plot_fdr=False):

    handles = [local_plot_hemispheres(slm.t, ["t-values"], (-4, 4), "bwr")]

    plot_pvalues = [np.copy(slm.P["pval"]["C"])]
    labels = ["Cluster p-values"]

    if plot_peak:
        plot_pvalues.append(np.copy(slm.P["pval"]["P"]))
        labels.append("Peak p-values")

    if plot_fdr:
        plot_pvalues.append(np.copy(slm.Q))
        labels.append("Vertex p-values")

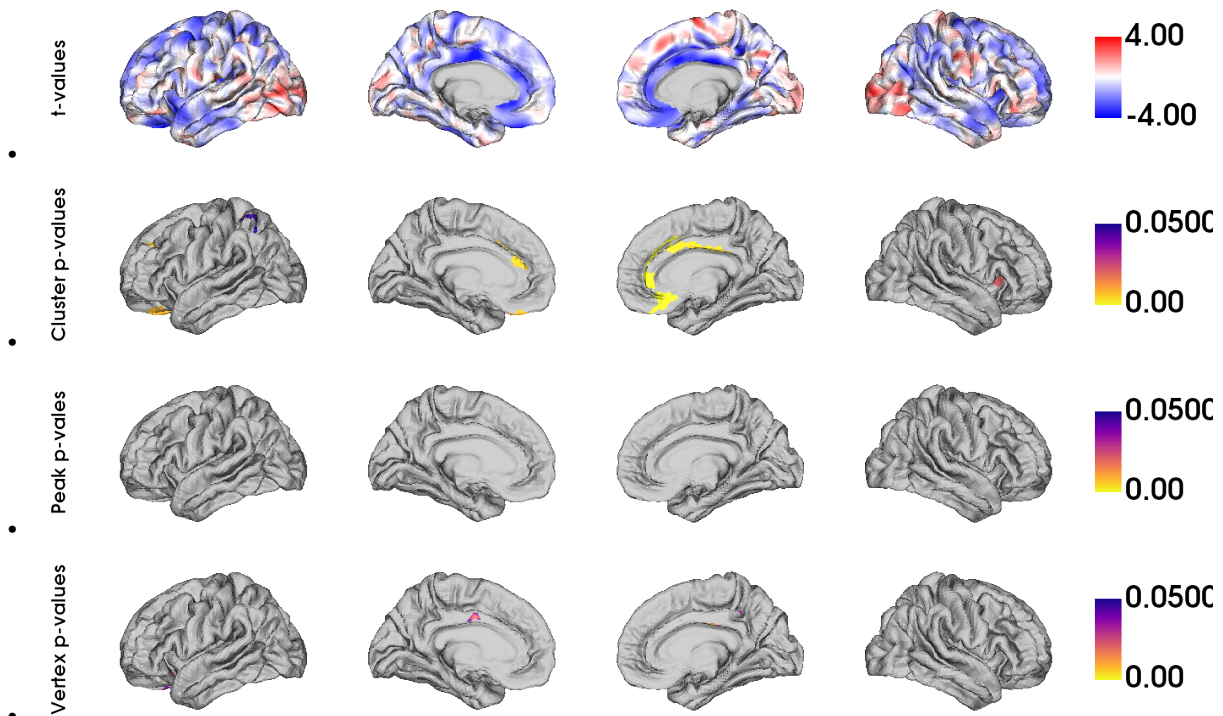
    [np.place(x, np.logical_or(x > 0.05, ~mask), np.nan) for x in plot_pvalues]

    for i in range(len(plot_pvalues)):
        handles.append(
            local_plot_hemispheres(plot_pvalues[i], [labels[i]], (0, 0.05), "plasma_r
→")
        )

    return handles

plot_slm_results(slm_age, plot_peak=True, plot_fdr=True)

```



Out:

```

[<IPython.core.display.Image object>, <IPython.core.display.Image object>, <IPython.
→core.display.Image object>, <IPython.core.display.Image object>]

```

Only clusters are significant, and not peaks. This suggests that the age effect covers large regions, rather than local foci. Furthermore, at the vertexwise level we only find a small group of significant vertices in the left cingulate cortex. Lets have a closer look at the clusters and their peaks. The data on clusters are stored in tables inside `BrainStatModel.P.clus` and information on the peaks is stored in `BrainStatModel.P.peak`. If a two-tailed test is run (BrainStat defaults to two-tailed), a table is returned for each tail. The first table uses the contrast as provided, the second table uses the inverse contrast. If a one-tailed test is performed, then only a single table is returned. Lets print the first 15 rows of the inverted contrast cluster table.

```
print(slm_age.P["clus"][1])
```

Out:

	clusid	nverts	resels	P
0	1	141.0	6.283315	0.000033
1	2	82.0	3.994467	0.001858
2	3	69.0	3.871711	0.002362
3	4	61.0	3.670485	0.003517
4	5	82.0	3.652319	0.003648
..
73	74	1.0	0.050811	1.000000
74	75	1.0	0.043958	1.000000
75	76	1.0	0.039022	1.000000
76	77	1.0	0.032002	1.000000
77	78	1.0	0.019503	1.000000

[78 rows x 4 columns]

Here, we see that cluster 1 contains 373 vertices. Clusters are sorted by p-value; later clusters will generally be smaller and have higher p-values. Lets now have a look at the peaks within these clusters.

```
print(slm_age.P["peak"][1])
```

Out:

	t	vertid	clusid	P	yeo7
0	5.695420	18720	11	0.001248	Ventral Attention
1	5.164823	5430	12	0.009035	Limbic
2	4.855500	16911	6	0.027242	Ventral Attention
3	4.833974	19629	2	0.029335	Frontoparietal
4	4.628306	12603	14	0.059519	Default mode
..
109	2.403000	2276	62	23.356468	Ventral Attention
110	2.394788	2185	74	23.709038	Default mode
111	2.389922	14687	76	23.918494	Default mode
112	2.382012	6087	64	24.258914	Default mode
113	2.375295	3243	72	24.548027	Default mode

[114 rows x 5 columns]

Within cluster 1, we are able to detect several peaks. The peak with the highest t-statistic ($t=4.3972$) occurs at vertex 19629, which is inside the frontoparietal network as defined by the Yeo-7 networks. Note that the Yeo network membership is only provided if the surface is specified as a template name as we did here. For custom surfaces, or pre-loaded surfaces (as we will use below) this column is omitted.

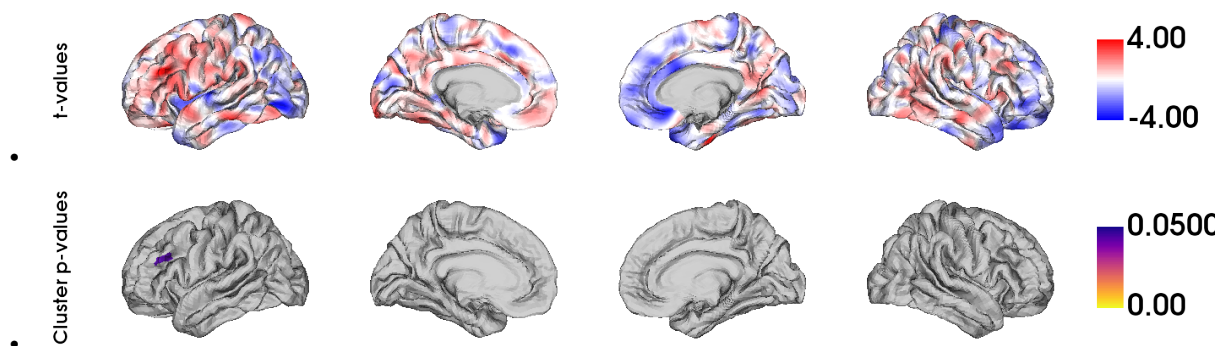
Interaction effects models

Similarly to age, we can also test for the effect of sex on cortical thickness.

```
term_sex = FixedEffect(demographics.SEX)
model_sex = term_sex
contrast_sex = (demographics.SEX == "M").astype(int) - (demographics.SEX == "F").
↳astype(
    int
)
```

Next we will rerun the model and see if our results change.

```
slm_sex = SLM(
    model_sex,
    contrast_sex,
    surf=pial_combined,
    mask=mask,
    correction=["fdr", "rft"],
    two_tailed=False,
    cluster_threshold=0.01,
)
slm_sex.fit(thickness)
plot_slm_results(slm_sex)
```



Out:

```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

Here, we find few significant effects of sex on cortical thickness. However, as we've already established, age has an effect on cortical thickness. So we may want to correct for this effect before evaluating whether sex has an effect on cortical thickness. Let's make a new model that includes the effect of age.

```
model_sexage = term_age + term_sex
```

Next we will rerun the model and see if our results change.

```
slm_sexage = SLM(
    model_sexage,
    contrast_sex,
    surf=pial_combined,
    mask=mask,
    correction=["fdr", "rft"],
    two_tailed=False,
```

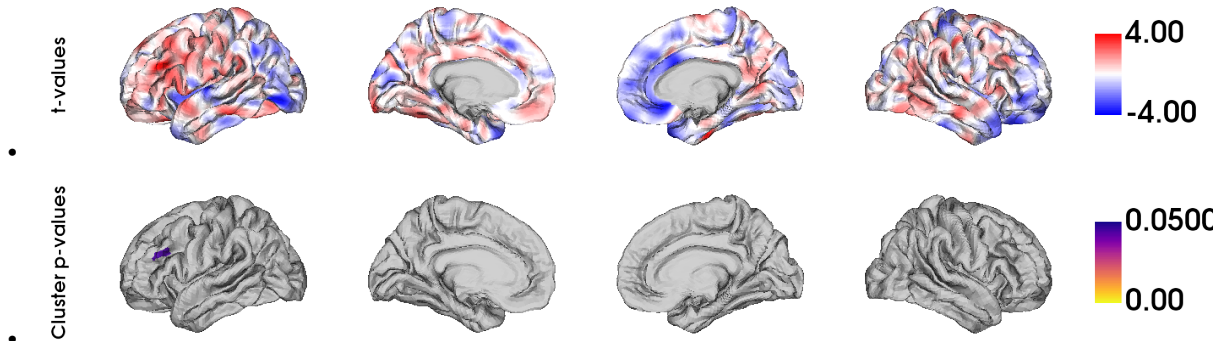
(continues on next page)

(continued from previous page)

```

cluster_threshold=0.01,
)
slm_sexage.fit(thickness)
plot_slm_results(slm_sexage)

```



Out:

```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

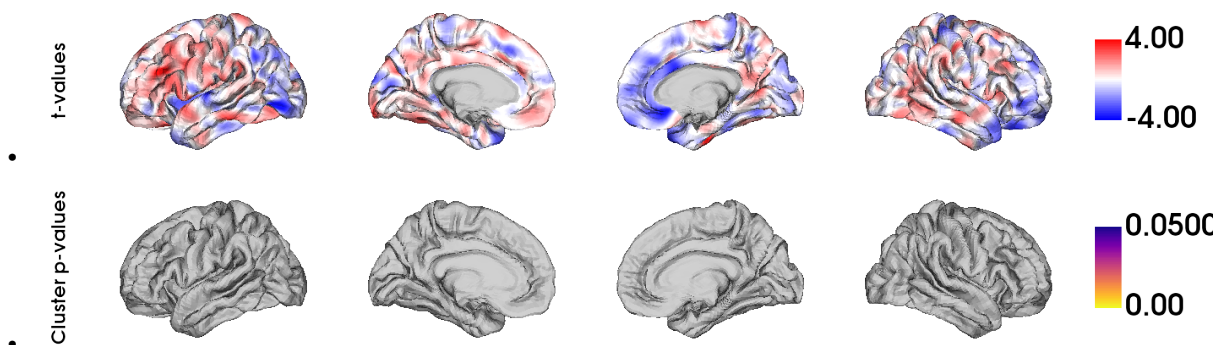
After accounting for the effect of age, we still find only one significant cluster of effect of sex on cortical thickness. However, it could be that age affects men and women differently. To account for this, we could include an interaction effect into the model. Lets run the model again with an interaction effect.

```

# Effect of sex on cortical thickness.
model_sexage_int = term_age + term_sex + term_age * term_sex

slm_sexage_int = SLM(
    model_sexage_int,
    contrast_sex,
    surf=pial_combined,
    mask=mask,
    correction=["rft"],
    cluster_threshold=0.01,
)
slm_sexage_int.fit(thickness)
plot_slm_results(slm_sexage_int)

```



Out:

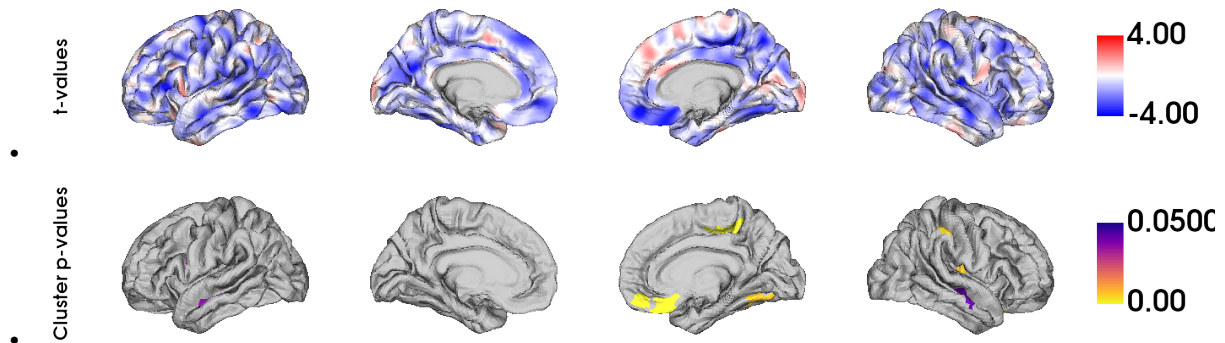
```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

After including the interaction effect, we no significant effects of sex on cortical thickness in several clusters.

We could also look at whether the cortex of men and women changes differently with age by comparing their interaction effects.

```
# Effect of age on cortical thickness for the healthy group.
contrast_sex_int = demographics.AGE_AT_SCAN * (
    demographics.SEX == "M"
) - demographics.AGE_AT_SCAN * (demographics.SEX == "F")

slm_sex_int = SLM(
    model_sexage_int,
    contrast_sex_int,
    surf=pial_combined,
    mask=mask,
    correction=["rft"],
    cluster_threshold=0.01,
)
slm_sex_int.fit(thickness)
plot_slm_results(slm_sex_int)
```



Out:

```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

Indeed, it appears that the interaction effect between sex and age is quite different across men and women, with stronger effects occurring in women.

One-tailed Test

Imagine that, based on prior research, we hypothesize that men have higher cortical thickness than women. In that case, we could run this same model with a one-tailed test, rather than a two-tailed test. By default BrainStat uses a two-tailed test. If you want to get a one-tailed test, simply specify it in the SLM model initialization with 'two_tailed', false. Note that the one-tailed test will test for the significance of positive t-values. If you want to test for the significance of negative t-values, simply change the sign of the contrast. We may hypothesize based on prior research that cortical thickness decreases with age, so we could specify this as follows. Note the minus in front of contrast_age to test for decreasing thickness with age.

```
from brainstat.stats.SLM import SLM

slm_onetailed = SLM(
    model_sexage_int,
    -contrast_age,
```

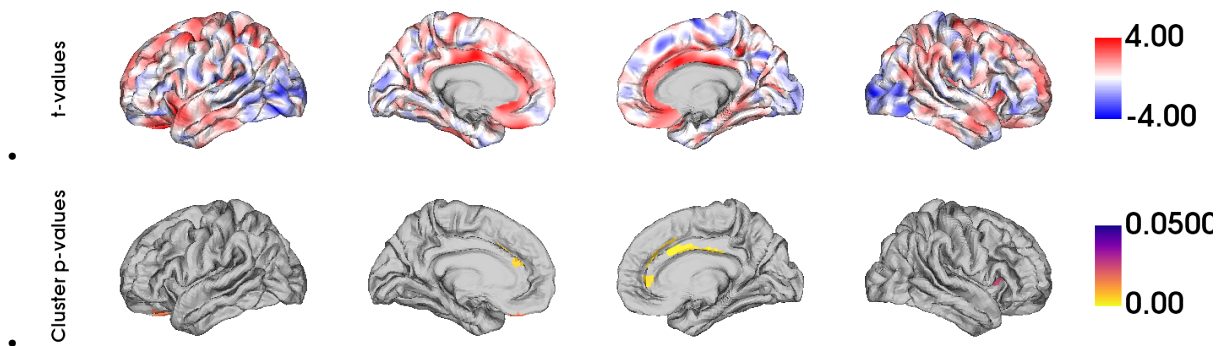
(continues on next page)

(continued from previous page)

```

surf=pial_combined,
mask=mask,
correction=["rft"],
cluster_threshold=0.01,
two_tailed=False,
)
slm_onetailed.fit(thickness)
plot_slm_results(slm_onetailed)

```



Out:

```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

Notice the additional clusters that we find when using a one-tailed test.

Mixed Effects Models

So far, we've considered multiple visits of the same subject as two separate, independent measurements. Clearly, however, such measurements are not independent of each other. To account for this, we could add subject ID as a random effect. Lets do this and test the effect of age on cortical thickness again.

```

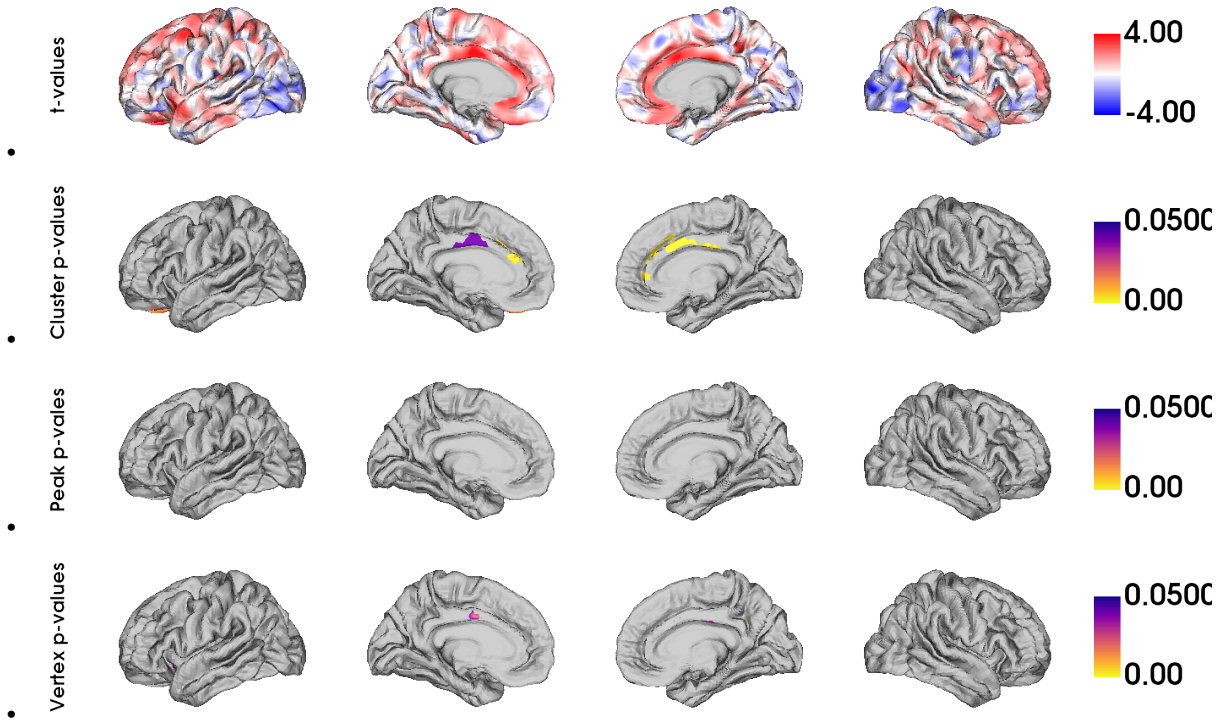
from brainstat.stats.terms import MixedEffect

term_subject = MixedEffect(demographics.SUB_ID)

model_mixed = term_age + term_sex + term_age * term_sex + term_subject

slm_mixed = SLM(
    model_mixed,
    -contrast_age,
    surf=pial_combined,
    mask=mask,
    correction=["fdr", "rft"],
    cluster_threshold=0.01,
    two_tailed=False,
)
slm_mixed.fit(thickness)
plot_slm_results(slm_mixed, True, True)

```



Out:

```
[<IPython.core.display.Image object>, <IPython.core.display.Image object>, <IPython.core.display.Image object>, <IPython.core.display.Image object>]
```

Compared to our first age model, we find fewer and smaller clusters, indicating that by not accounting for the repeated measures structure of the data we were overestimating the significance of effects.

That concludes the basic usage of the BrainStat for statistical models. In the next tutorial we'll show you how to use the context decoding module.

Total running time of the script: (0 minutes 13.555 seconds)

Tutorial 02: Context Decoding

In this tutorial you will learn about the context decoding tools included with BrainStat. The context decoding module consists of three parts: genetic decoding, meta-analytic decoding and histological comparisons. Before we start, let's run a linear model testing for the effects of age on cortical thickness as we did in Tutorial 1. We'll use the results of this model later in this tutorial.

```
from brainstat.datasets import fetch_mask, fetch_template_surface
from brainstat.stats.SLM import SLM
from brainstat.stats.terms import FixedEffect, MixedEffect
from brainstat.tutorial.utils import fetch_mics_data

thickness, demographics = fetch_mics_data()
mask = fetch_mask("fsaverage5")

term_age = FixedEffect(demographics.AGE_AT_SCAN)
term_sex = FixedEffect(demographics.SEX)
term_subject = MixedEffect(demographics.SUB_ID)
```

(continues on next page)

(continued from previous page)

```

model = term_age + term_sex + term_age * term_sex + term_subject

contrast_age = -model.mean.AGE_AT_SCAN
slm = SLM(
    model,
    contrast_age,
    surf="fsaverage5",
    mask=mask,
    correction=["fdr", "rft"],
    two_tailed=False,
    cluster_threshold=0.01,
)
slm.fit(thickness)

```

Genetics

For genetic decoding we use the Allen Human Brain Atlas through the abagen toolbox. Note that abagen only accepts parcellated data. Here is a minimal example of how we use abagen to get the genetic expression of the 100 regions of the Schaefer atlas and how to plot this expression to a matrix. Please note that downloading the dataset and running this analysis can take several minutes.

```

import copy

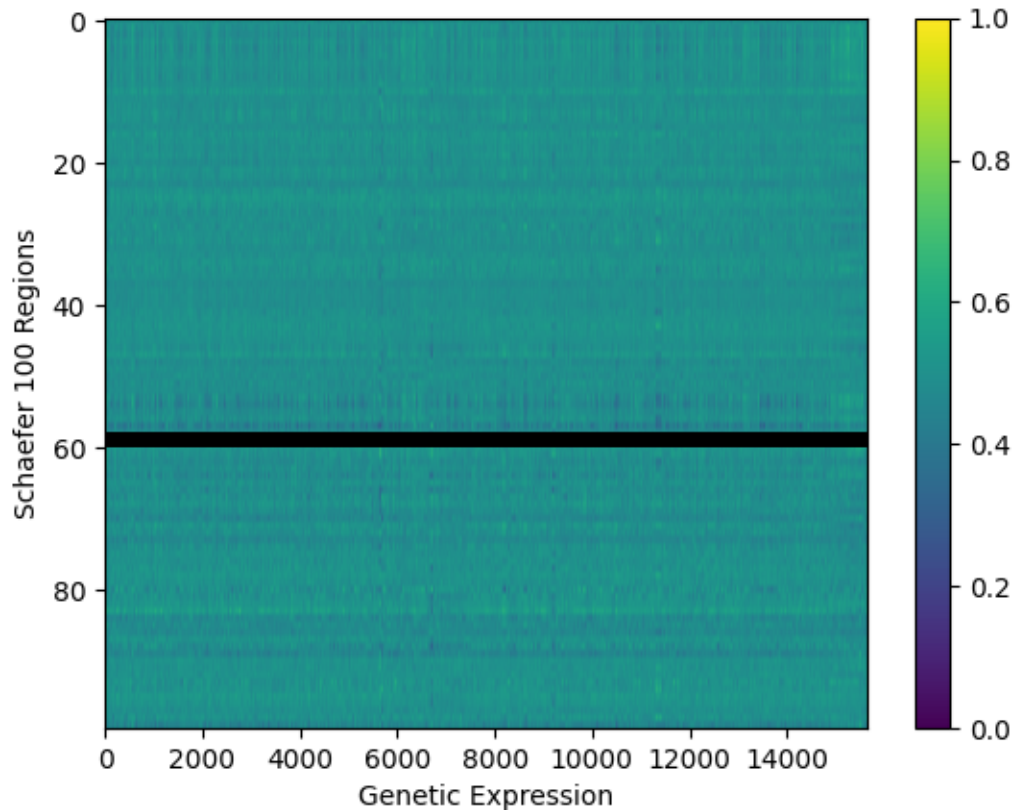
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from brainspace.utils.parcellation import reduce_by_labels
from matplotlib.cm import get_cmap

from brainstat.context.genetics import surface_genetic_expression
from brainstat.datasets import fetch_parcellation

# Get Schaefer-100 genetic expression.
schaefer_100_fs5 = fetch_parcellation("fsaverage5", "schaefer", 100)
surfaces = fetch_template_surface("fsaverage5", join=False)
expression = surface_genetic_expression(schaefer_100_fs5, surfaces, space="fsaverage")

# Plot Schaefer-100 genetic expression matrix.
colormap = copy.copy(get_cmap())
colormap.set_bad(color="black")
plt.imshow(expression, aspect="auto", cmap=colormap)
plt.colorbar()
plt.xlabel("Genetic Expression")
plt.ylabel("Schaefer 100 Regions")
plt.show()

```

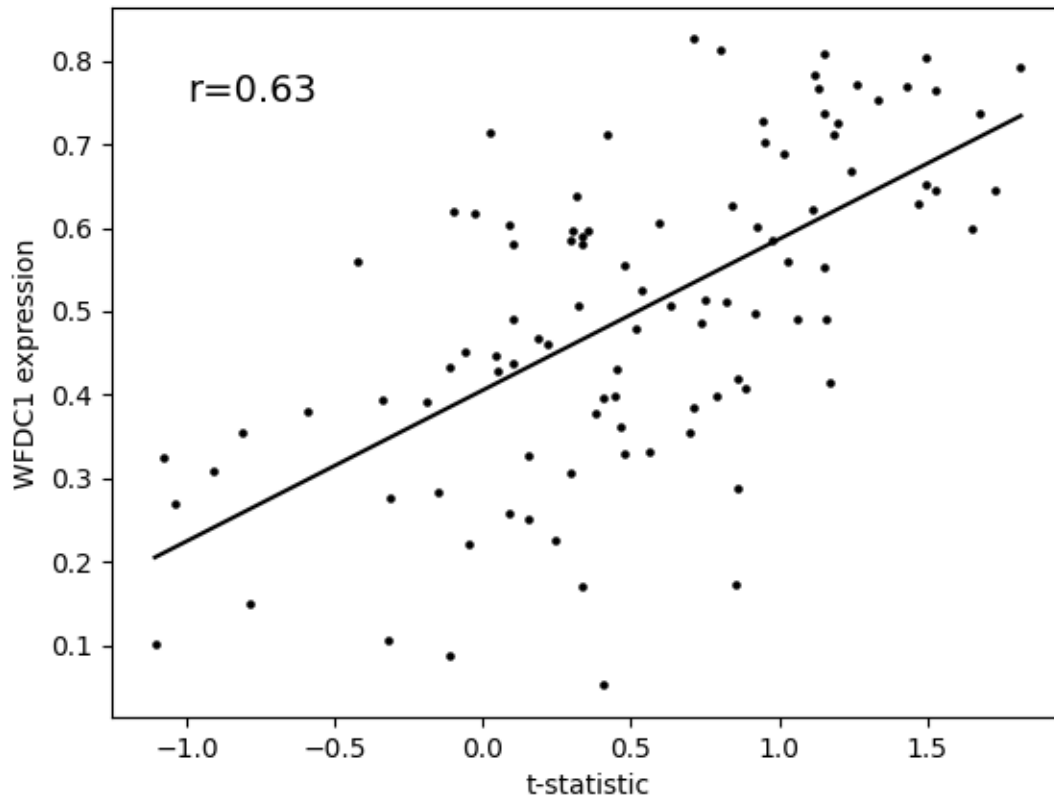



Expression is a pandas DataFrame which shows the genetic expression of genes within each region of the atlas. By default, the values will fall in the range [0, 1] where higher values represent higher expression. However, if you change the normalization function then this may change. Some regions may return NaN values for all genes. This occurs when there are no samples within this region across all donors. We've denoted this region with the black color in the matrix. By default, BrainStat uses all the default abagen parameters. If you wish to customize these parameters then the keyword arguments can be passed directly to `surface_genetic_expression`. For a full list of these arguments and their function please consult the abagen documentation.

Next, let's have a look at the correlation between one gene (WFDC1) and our t-statistic map. Let's also plot the expression of this gene to the surface.

```
# Plot correlation with WFDC1 gene
t_stat_schaefer_100 = reduce_by_labels(slm.t.flatten(), schaefer_100_fs5)[1:]

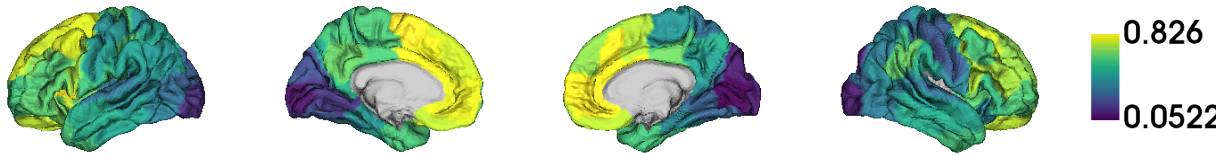
df = pd.DataFrame({"x": t_stat_schaefer_100, "y": expression["WFDC1"]})
df.dropna(inplace=True)
plt.scatter(df.x, df.y, s=5, c="k")
plt.xlabel("t-statistic")
plt.ylabel("WFDC1 expression")
plt.plot(np.unique(df.x), np.poly1d(np.polyfit(df.x, df.y, 1))(np.unique(df.x)), "k")
plt.text(-1.0, 0.75, f"r={df.x.corr(df.y):.2f}", fontdict={"size": 14})
plt.show()
```



```
# Plot WFDC1 gene to the surface.
from brainspace.plotting.surface_plotting import plot_hemispheres
from brainspace.utils.parcellation import map_to_labels

vertexwise_WFDC1 = map_to_labels(
    expression["WFDC1"].to_numpy(),
    schaefer_100_fs5,
    mask=schaefer_100_fs5 != 0,
    fill=np.nan,
)

plot_hemispheres(
    surfaces[0],
    surfaces[1],
    vertexwise_WFDC1,
    color_bar=True,
    embed_nb=True,
    size=(1400, 200),
    zoom=1.45,
    nan_color=(0.7, 0.7, 0.7, 1),
    cb__labelTextProperty={"fontSize": 12},
)
```

Out:

```
/Users/reinder/opt/miniconda3/envs/python3.8/lib/python3.8/site-packages/brainspace/
↳plotting/base.py:287: UserWarning:

Interactive mode requires 'panel'. Setting 'interactive=False'

<IPython.core.display.Image object>
```

We find a small correlation. To test for significance we'll have to do some additional corrections, but more on that later.

Meta-Analytic

To perform meta-analytic decoding, BrainStat uses precomputed Neurosynth maps. Here we test which terms are most associated with a map of cortical thickness. A simple example analysis can be run as follows. The surface decoder interpolates the data from the surface to the voxels in the volume that are in between the two input surfaces. We'll decode the t-statistics derived with our model earlier. Note that downloading the dataset and running this analysis can take several minutes.

```
from brainstat.context.meta_analysis import meta_analytic_decoder

meta_analysis = meta_analytic_decoder("fsaverage5", slm.t.flatten())
print(meta_analysis)
```

Out:

```

                Pearson's r
nucleus accumbens    0.207755
accumbens            0.207571
dorsal anterior      0.201299
dacc                 0.197329
ventral striatum     0.194612
...
selectivity          -0.225116
object recognition    -0.230603
v1                   -0.232651
lateral occipital     -0.232874
sighted              -0.249728

[3228 rows x 1 columns]
```

meta_analysis now contains a pandas.dataFrame with the correlation values for each requested feature. Next we could create a Wordcloud of the included terms, wherein larger words denote higher correlations.

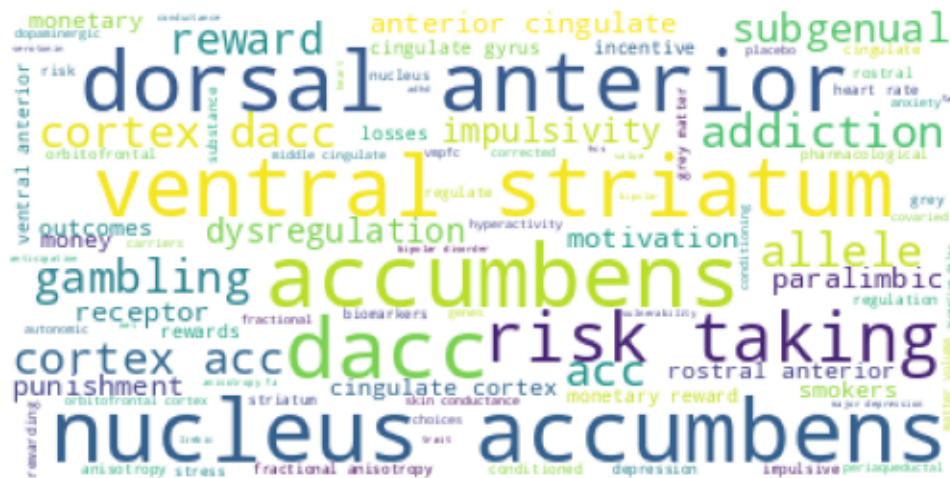
```
from wordcloud import WordCloud

wc = WordCloud(background_color="white", random_state=0)
```

(continues on next page)

(continued from previous page)

```
wc.generate_from_frequencies(frequencies=meta_analysis.to_dict()["Pearson's r"])
plt.imshow(wc)
plt.axis("off")
plt.show()
```



If we broadly summarize, we see a lot of words related to language e.g., “language comprehension”, “broca”, “speaking”, “speech production”. Generally you’ll also find several hits related to anatomy or clinical conditions. Depending on your research question, it may be more interesting to select only those terms related to cognition or some other subset.

Histological decoding

For histological decoding we use microstructural profile covariance gradients, as first shown by (Paquola et al, 2019, Plos Biology), computed from the BigBrain dataset. Firstly, lets download the MPC data, compute and plot its gradients, and correlate the first gradient with our t-statistic map.

```
from brainstat.context.histology import (
    compute_histology_gradients,
    compute_mpc,
    read_histology_profile,
)
```

(continues on next page)

(continued from previous page)

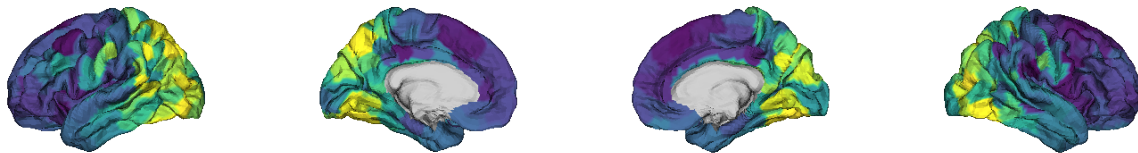
```

# Run the analysis
schaefer_400 = fetch_parcellation("fsaverage5", "schaefer", 400)
histology_profiles = read_histology_profile(template="fsaverage5")
mpc = compute_mpc(histology_profiles, labels=schaefer_400)
gradient_map = compute_histology_gradients(mpc, random_state=0)

# Bring parcellated data to vertex data.
vertexwise_gradient = map_to_labels(
    gradient_map.gradients[:, 0],
    schaefer_400,
    mask=schaefer_400 != 0,
    fill=np.nan,
)

plot_hemispheres(
    surfaces[0],
    surfaces[1],
    vertexwise_gradient,
    embed_nb=True,
    nan_color=(0.7, 0.7, 0.7, 1),
    size=(1400, 200),
    zoom=1.45,
)

```



Out:

```

/Users/reinder/GitHub/BrainStat/brainstat/context/histology.py:105: RuntimeWarning:
divide by zero encountered in true_divide

/Users/reinder/GitHub/BrainStat/brainstat/context/histology.py:105: RuntimeWarning:
invalid value encountered in log

/Users/reinder/opt/miniconda3/envs/python3.8/lib/python3.8/site-packages/brainspace/
plotting/base.py:287: UserWarning:

Interactive mode requires 'panel'. Setting 'interactive=False'

<IPython.core.display.Image object>

```

```

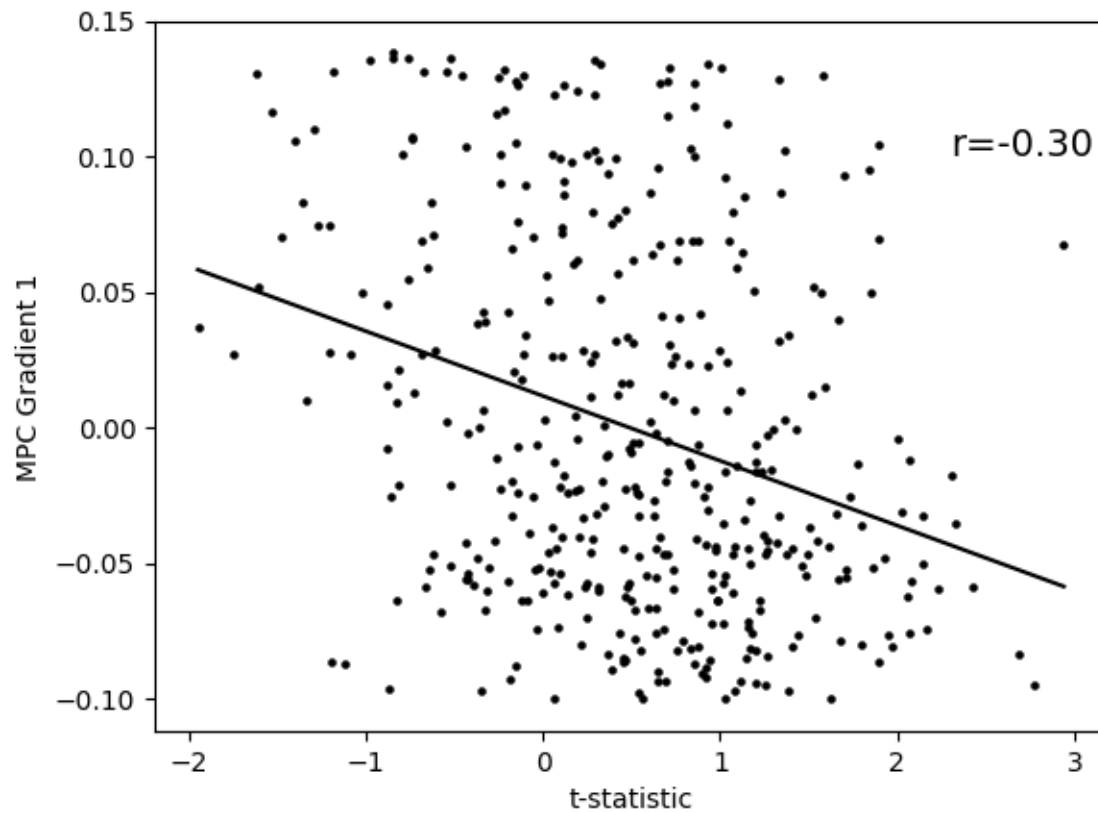
# Plot the correlation between the t-stat
t_stat_schaefer_400 = reduce_by_labels(slm.t.flatten(), schaefer_400)[1:]
df = pd.DataFrame({"x": t_stat_schaefer_400, "y": gradient_map.gradients[:, 0]})
df.dropna(inplace=True)
plt.scatter(df.x, df.y, s=5, c="k")
plt.xlabel("t-statistic")
plt.ylabel("MPC Gradient 1")

```

(continues on next page)

(continued from previous page)

```
plt.plot(np.unique(df.x), np.poly1d(np.polyfit(df.x, df.y, 1))(np.unique(df.x)), "k")
plt.text(2.3, 0.1, f"r=(df.x.corr(df.y) :.2f)", fontdict={"size": 14})
plt.show()
```



The variable `histology_profiles` now contains histological profiles sampled at 50 different depths across the cortex, `mpc` contains the covariance of these profiles, and `gradient_map` contains their gradients. We also see that the correlation between our t-statistic map and these gradients is not very high. Depending on your use-case, each of the three variables here could be of interest, but for purposes of this tutorial we'll plot the gradients to the surface with `BrainSpace`. For details on what the `GradientMaps` class (`gradient_map`) contains please consult the `BrainSpace` documentation.

```
from brainspace.utils.parcellation import map_to_labels

surfaces = fetch_template_surface("fsaverage5", join=False)

# Bring parcellated data to vertex data.
vertexwise_data = []
for i in range(0, 2):
    vertexwise_data.append(
        map_to_labels(
            gradient_map.gradients[:, i],
            schaefer_400,
            mask=schaefer_400 != 0,
            fill=np.nan,
        )
    )
```

(continues on next page)

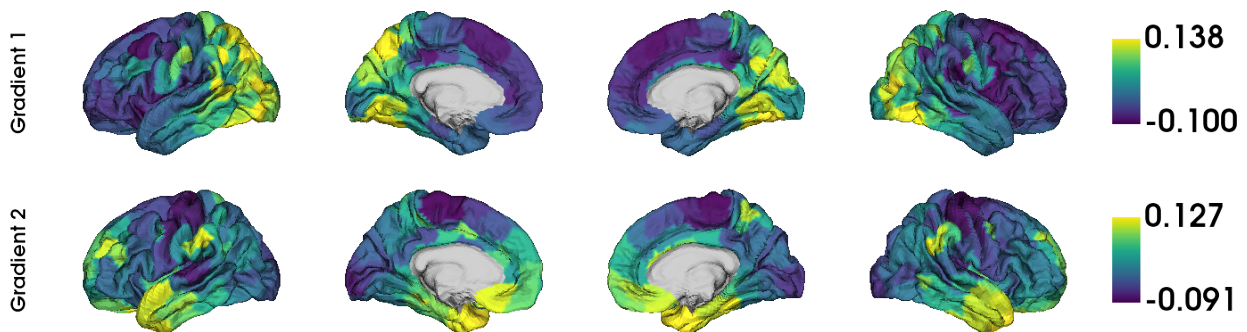
(continued from previous page)

```

)

# Plot to surface.
plot_hemispheres(
    surfaces[0],
    surfaces[1],
    vertexwise_data,
    embed_nb=True,
    label_text=["Gradient 1", "Gradient 2"],
    color_bar=True,
    size=(1400, 400),
    zoom=1.45,
    nan_color=(0.7, 0.7, 0.7, 1),
    cb_labelTextProperty={"fontSize": 12},
)

```



Out:

```

/Users/reinder/opt/miniconda3/envs/python3.8/lib/python3.8/site-packages/brainspace/
plotting/base.py:287: UserWarning:

Interactive mode requires 'panel'. Setting 'interactive=False'

<IPython.core.display.Image object>

```

Note that we no longer use the y-axis regression used in (Paquola et al, 2019, Plos Biology), as such the first gradient becomes an anterior-posterior gradient.

Resting-state contextualization

Lastly, BrainStat provides contextualization using resting-state fMRI markers: specifically, with the Yeo functional networks (Yeo et al., 2011, Journal of Neurophysiology), a clustering of resting-state connectivity, and the functional gradients (Margulies et al., 2016, PNAS), a lower dimensional manifold of resting-state connectivity.

As an example, let's have a look at the t-statistic map within the Yeo networks. We'll plot the Yeo networks as well as a barplot showing the mean and standard error of the mean within each network.

```

from brainstat.datasets import fetch_yeo_networks_metadata
from matplotlib.colors import ListedColormap

yeo_networks = fetch_parcellation("fsaverage5", "yeo", 7)

```

(continues on next page)

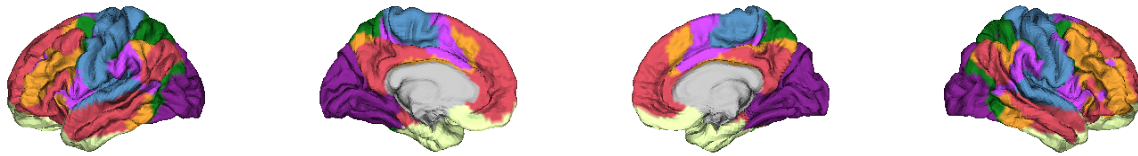
(continued from previous page)

```

network_names, yeo_colormap = fetch_yeo_networks_metadata(7)
yeo_colormap_gray = np.concatenate((np.array([[0.7, 0.7, 0.7]]), yeo_colormap))

plot_hemispheres(
    surfaces[0],
    surfaces[1],
    yeo_networks,
    embed_nb=True,
    cmap=ListedColormap(yeo_colormap_gray),
    nan_color=(0.7, 0.7, 0.7, 1),
    size=(1400, 200),
    zoom=1.45,
)

```



Out:

```

/Users/reinder/opt/miniconda3/envs/python3.8/lib/python3.8/site-packages/brainspace/
↳plotting/base.py:287: UserWarning:

Interactive mode requires 'panel'. Setting 'interactive=False'

<IPython.core.display.Image object>

```

```

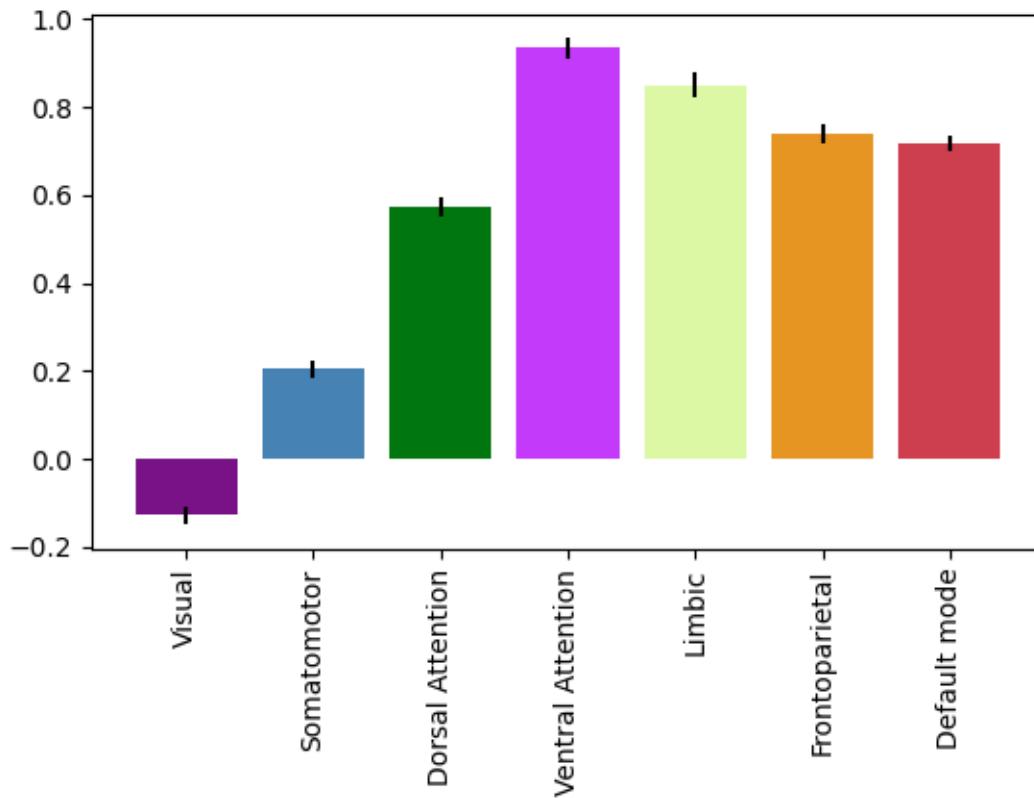
import matplotlib.pyplot as plt
from scipy.stats import sem

from brainstat.context.resting import yeo_networks_associations

yeo_tstat_mean = yeo_networks_associations(slm.t.flatten(), "fsaverage5")
yeo_tstat_sem = yeo_networks_associations(
    slm.t.flatten(),
    "fsaverage5",
    reduction_operation=lambda x, y: sem(x, nan_policy="omit"),
)

plt.bar(
    np.arange(7), yeo_tstat_mean[:, 0], yerr=yeo_tstat_sem.flatten(), color=yeo_
↳colormap
)
plt.xticks(np.arange(7), network_names, rotation=90)
plt.gcf().subplots_adjust(bottom=0.3)
plt.show()

```



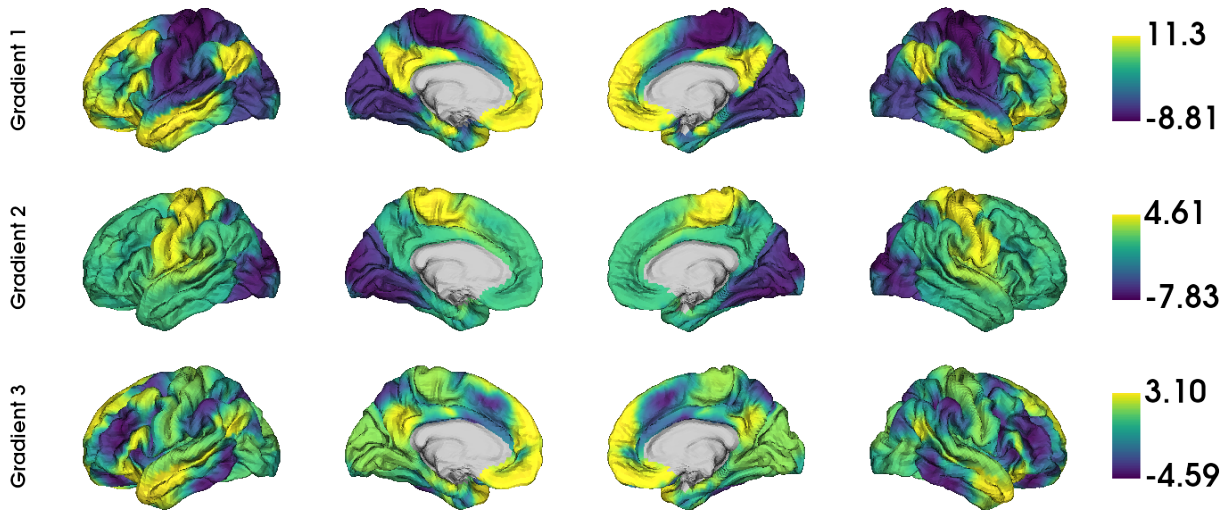
Across all networks, the mean t-statistic appears to be negative, with the most negative values in the dorsal attention and visual networks.

Lastly, let's plot the functional gradients and have a look at their correlation with our t-map.

```
from brainstat.datasets import fetch_gradients

functional_gradients = fetch_gradients("fsaverage5", "margulies2016")

plot_hemispheres(
    surfaces[0],
    surfaces[1],
    functional_gradients[:, 0:3].T,
    color_bar=True,
    label_text=["Gradient 1", "Gradient 2", "Gradient 3"],
    embed_nb=True,
    size=(1400, 600),
    zoom=1.45,
    nan_color=(0.7, 0.7, 0.7, 1),
    cb_labelTextProperty={"fontSize": 12},
)
```



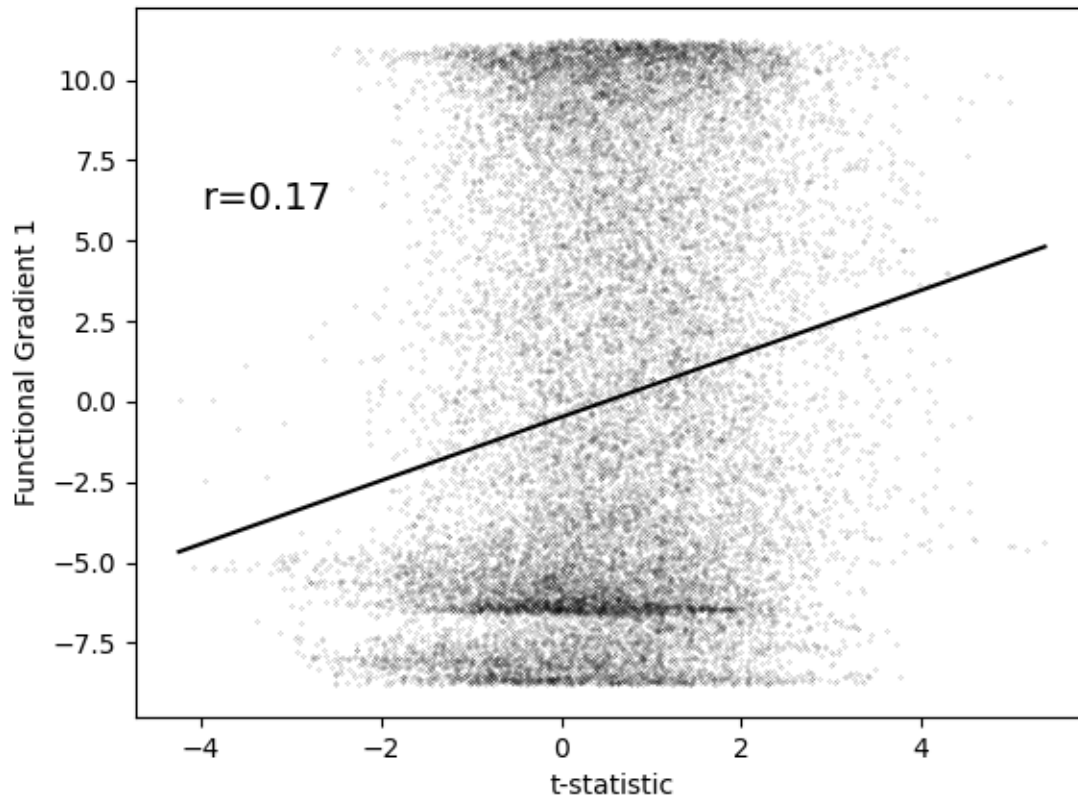
Out:

```
/Users/reinder/opt/miniconda3/envs/python3.8/lib/python3.8/site-packages/brainspace/
↳plotting/base.py:287: UserWarning:
```

```
Interactive mode requires 'panel'. Setting 'interactive=False'
```

```
<IPython.core.display.Image object>
```

```
df = pd.DataFrame({"x": slm.t.flatten(), "y": functional_gradients[:, 0]})
df.dropna(inplace=True)
plt.scatter(df.x, df.y, s=0.01, c="k")
plt.xlabel("t-statistic")
plt.ylabel("Functional Gradient 1")
plt.plot(np.unique(df.x), np.poly1d(np.polyfit(df.x, df.y, 1))(np.unique(df.x)), "k")
plt.text(-4.0, 6, f"r={df.x.corr(df.y):.2f}", fontdict={"size": 14})
plt.show()
```

It seems the correlations are quite low. However, we'll need some more complex tests to assess statistical significance. There are many ways to compare these gradients to cortical markers. In general, we recommend using corrections for spatial autocorrelation which are implemented in BrainSpace. We'll show a correction with spin test in this tutorial; for other methods and further details please consult the BrainSpace tutorials.

In a spin test we compare the empirical correlation between the gradient and the cortical marker to a distribution of correlations derived from data rotated across the cortical surface. The p-value then depends on the percentile of the empirical correlation within the permuted distribution.

```
from brainspace.null_models import SpinPermutations

sphere_left, sphere_right = fetch_template_surface(
    "fsaverage5", layer="sphere", join=False
)
tstat = slm.t.flatten()
tstat_left = tstat[: slm.t.size // 2]
tstat_right = tstat[slm.t.size // 2 :]

# Run spin test with 1000 permutations.
n_rep = 1000
sp = SpinPermutations(n_rep=n_rep, random_state=2021)
sp.fit(sphere_left, points_rh=sphere_right)
tstat_rotated = np.hstack(sp.randomize(tstat_left, tstat_right))

# Compute correlation for empirical and permuted data.
mask = ~np.isnan(functional_gradients[:, 0]) & ~np.isnan(tstat)
```

(continues on next page)

(continued from previous page)

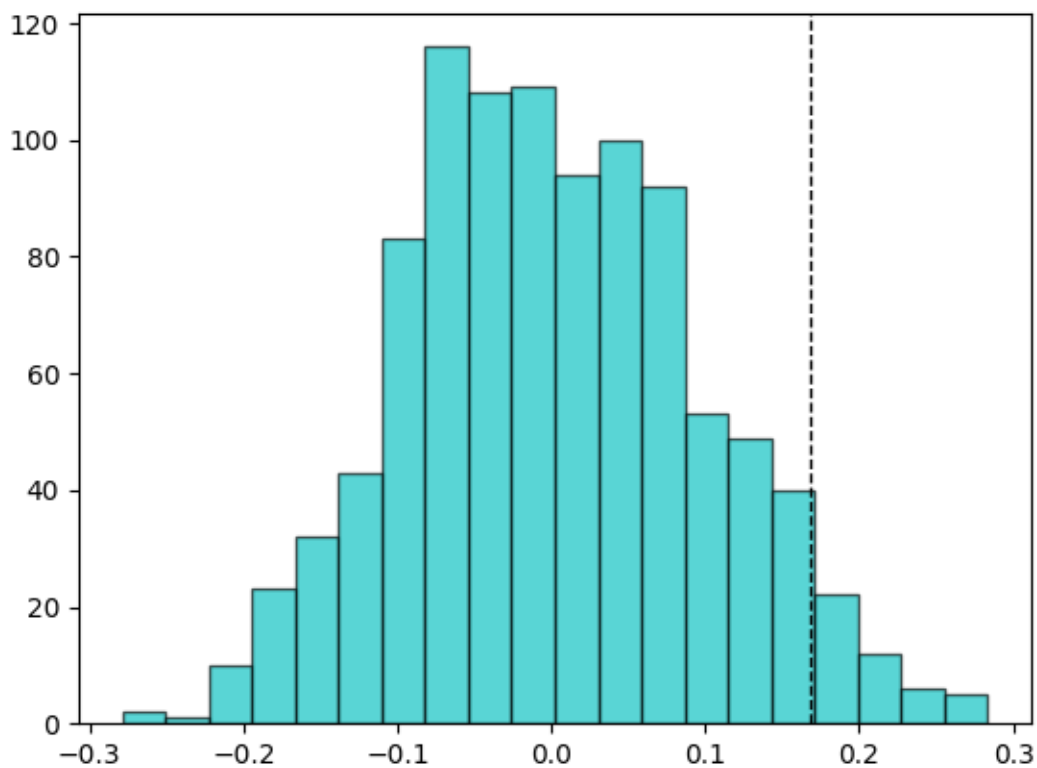
```

r_empirical = np.corrcoef(functional_gradients[mask, 0], tstat[mask])[0, 1]
r_permuted = np.zeros(n_rep)
for i in range(n_rep):
    mask = ~np.isnan(functional_gradients[:, 0]) & ~np.isnan(tstat_rotated[i, :])
    r_permuted[i] = np.corrcoef(functional_gradients[mask, 0], tstat_rotated[i,
↪mask])[
        1:, 0
    ]

# Significance depends on whether we do a one-tailed or two-tailed test.
# If one-tailed it depends on in which direction the test is.
p_value_right_tailed = np.mean(r_empirical > r_permuted)
p_value_left_tailed = np.mean(r_empirical < r_permuted)
p_value_two_tailed = np.minimum(p_value_right_tailed, p_value_left_tailed) * 2
print(f"Two tailed p-value: {p_value_two_tailed}")

# Plot the permuted distribution of correlations.
plt.hist(r_permuted, bins=20, color="c", edgecolor="k", alpha=0.65)
plt.axvline(r_empirical, color="k", linestyle="dashed", linewidth=1)
plt.show()

```



Out:

```
Two tailed p-value: 0.094
```

As we can see from both the p-value as well as the histogram, wherein the dotted line denotes the empirical correlation, this correlation does not reach significance.

That concludes the tutorials of BrainStat. If anything is unclear, or if you think you've found a bug, please post it to the Issues page of our Github.

Happy BrainStating!

Total running time of the script: (4 minutes 12.472 seconds)

3.2.2 API

Neuroimaging statistics toolbox.

Modules

<code>brainstat.context</code>	BrainStat's context decoding module.
<code>brainstat.datasets</code>	Data included with BrainStat.
<code>brainstat.mesh</code>	Module for the handling of meshes and mesh data.
<code>brainstat.stats</code>	The statistics tools of BrainStat
<code>brainstat.tests</code>	Unit tests and their data generation.
<code>brainstat.tutorial</code>	Functions required for the BrainStat Tutorials

brainstat.context

BrainStat's context decoding module.

Modules

<code>brainstat.context.genetics</code>	Genetic decoding using abagen.
<code>brainstat.context.histology</code>	Histology context decoder
<code>brainstat.context.meta_analysis</code>	Meta-analytic decoding based on NiMARE
<code>brainstat.context.resting</code>	

brainstat.context.genetics

Genetic decoding using abagen.

Functions

<code>surface_genetic_expression(labels[, ...])</code>	Computes genetic expression of surface parcels.
--	---

brainstat.context.genetics.surface_genetic_expression

```
brainstat.context.genetics.surface_genetic_expression (labels,          surfaces=None,
                                                         space=None,          *,
                                                         atlas_info=None,
                                                         ibf_threshold=0.5,
                                                         probe_selection='diff_stability',
                                                         donor_probes='aggregate',
                                                         lr_mirror=None,          miss-
                                                         ing=None,          tolerance=2,
                                                         sample_norm='srs',
                                                         gene_norm='srs',
                                                         norm_matched=True,
                                                         norm_structures=False,
                                                         region_agg='donors',
                                                         agg_metric='mean',          cor-
                                                         rected_mni=True,          re-
                                                         annotated=True,          re-
                                                         turn_counts=False,          re-
                                                         turn_donors=False,
                                                         return_report=False,
                                                         donors='all', data_dir=None,
                                                         verbose=0, n_proc=1)
```

Computes genetic expression of surface parcels.

Parameters

- **labels** (*list-of-str* or *numpy.ndarray*) – List of paths to label files for the parcellation, or numpy array containing the pre-loaded labels
- **surfaces** (*list-of-image*, *optional*) – List of paths to surface files or preloaded surfaces. If not specified assumes that *labels* are on the *fsaverage5* surface. Default: None
- **space** (*{'fsaverage', 'fs1r'}*) – What template space *surfaces* are aligned to. If not specified assumes that *labels* are on the *fsaverage5* surface. Default: None
- **details of the remaining parameters please consult the (For) –**
- **documentation. All its parameters bar "atlas"** (*abagen.get_expression_data()*) –
- **valid input parameters. (are) –**

Returns *pandas.DataFrame* – Dataframe containing the expression of each gene within each region.

Examples

```
>>> from brainstat.context.genetics import surface_genetic_expression
>>> from nilearn import datasets
>>> import numpy as np
```

```
>>> destrieux = datasets.fetch_atlas_surf_destrieux()
>>> labels = np.hstack((destrieux['map_left'], destrieux['map_right']))
>>> fsaverage = datasets.fetch_surf_fsaverage()
>>> surfaces = (fsaverage['pial_left'], fsaverage['pial_right'])
>>> expression = surface_genetic_expression(labels, surfaces,
...                                         space='fsaverage')
```

brainstat.context.histology

Histology context decoder

Functions

<code>compute_histology_gradients(mpc[, kernel, ...])</code>	Computes microstructural profile covariance gradients.
<code>compute_mpc(profile, labels)</code>	Computes MPC for given labels on a surface template.
<code>download_histology_profiles([data_dir, ...])</code>	Downloads BigBrain histology profiles.
<code>partial_correlation(X, covar)</code>	Runs a partial correlation whilst correcting for a covariate.
<code>read_histology_profile([data_dir, template, ...])</code>	Reads BigBrain histology profiles.

brainstat.context.histology.compute_histology_gradients

```
brainstat.context.histology.compute_histology_gradients(mpc,
                                                         kernel='normalized_angle',
                                                         approach='dm',
                                                         n_components=10,
                                                         alignment=None,
                                                         random_state=None,
                                                         gamma=None,
                                                         sparsity=0.9,
                                                         reference=None,
                                                         n_iter=10)
```

Computes microstructural profile covariance gradients.

Parameters

- **mpc** (*numpy.ndarray*) – Microstructural profile covariance matrix.
- **kernel** (*str, optional*) – Kernel function to build the affinity matrix. Possible options: {'pearson', 'spearman', 'cosine', 'normalized_angle', 'gaussian'}. If callable, must receive a 2D array and return a 2D square array. If None, use input matrix. By default “normalized_angle”.

- **approach** (*str*, *optional*) – Embedding approach. Can be ‘pca’ for Principal Component Analysis, ‘le’ for laplacian eigenmaps, or ‘dm’ for diffusion mapping, by default “dm”.
- **n_components** (*int*, *optional*) – Number of components to return, by default 10.
- **alignment** (*str*, *None*, *optional*) – Alignment approach. Only used when two or more datasets are provided. Valid options are ‘pa’ for procrustes analysis and “joint” for joint embedding. If None, no alignment is performed, by default None.
- **random_state** (*int*, *None*, *optional*) – Random state, by default None
- **gamma** (*float*, *None*, *optional*) – Inverse kernel width. Only used if kernel == “gaussian”. If None, gamma=1/n_feat, by default None.
- **sparsity** (*float*, *optional*) – Proportion of smallest elements to zero-out for each row, by default 0.9.
- **reference** (*numpy.ndarray*, *optional*) – Initial reference for procrustes alignments. Only used when alignment == ‘procrustes’, by default None.
- **n_iter** (*int*, *optional*) – Number of iterations for Procrustes alignment, by default 10.

Returns *brainspace.gradient.gradient.GradientMaps* – BrainSpace gradient maps object.

brainstat.context.histology.compute_mpc

`brainstat.context.histology.compute_mpc(profile, labels)`

Computes MPC for given labels on a surface template.

Parameters

- **profile** (*numpy.ndarray*) – Histological profiles of size surface-by-vertex.
- **labels** (*numpy.ndarray*) – Labels of regions of interest. Use 0 to denote regions that will not be included.

Returns *numpy.ndarray* – Microstructural profile covariance.

brainstat.context.histology.download_histology_profiles

`brainstat.context.histology.download_histology_profiles(data_dir=None, template='fsaverage', overwrite=False)`

Downloads BigBrain histology profiles.

Parameters

- **data_dir** (*str*, *pathlib.Path*, *None*, *optional*) – Path to the directory to store the data. If None, defaults to the home directory, by default None.
- **template** (*str*, *optional*) – Surface template. Currently allowed options are ‘fsaverage’ and ‘fsLR32k’, by default ‘fsaverage’.
- **overwrite** (*bool*, *optional*) – If true, existing data will be overwritten, by default False.

Raises **KeyError** – Thrown if an invalid template is requested.

brainstat.context.histology.partial_correlation

`brainstat.context.histology.partial_correlation(X, covar)`

Runs a partial correlation whilst correcting for a covariate.

Parameters

- **X** (*ArrayLike*) – Two-dimensional array of the data to be correlated.
- **covar** (*numpy.ndarray*) – One-dimensional array of the covariate.

Returns *numpy.ndarray* – Partial correlation matrix.

brainstat.context.histology.read_histology_profile

`brainstat.context.histology.read_histology_profile(data_dir=None, template='fsaverage', overwrite=False)`

Reads BigBrain histology profiles.

Parameters

- **data_dir** (*str, pathlib.Path, None, optional*) – Path to the data directory. If data is not found here then data will be downloaded. If None, data_dir is set to the home directory, by default None.
- **template** (*str, optional*) – Surface template. Currently allowed options are ‘fsaverage’ and ‘fsLR32k’, by default ‘fsaverage’.
- **overwrite** (*bool, optional*) – If true, existing data will be overwritten, by default False.

Returns *numpy.ndarray* – Depth-by-vertex array of BigBrain intensities.

brainstat.context.meta_analysis

Meta-analytic decoding based on NiMARE

Functions

<code>meta_analytic_decoder(template, stat_labels)</code>	Meta-analytic decoding of surface maps using NeuroSynth or NeuroQuery.
---	--

brainstat.context.meta_analysis.meta_analytic_decoder

`brainstat.context.meta_analysis.meta_analytic_decoder(template, stat_labels, data_dir=None)`

Meta-analytic decoding of surface maps using NeuroSynth or NeuroQuery.

Parameters

- **template** (*str*) – Path of a template volume file.
- **stat_labels** (*str, numpy.ndarray, sequence of str or numpy.ndarray*) – Path to a label file for the surfaces, numpy array containing the labels, or a

list containing multiple of the aforementioned.

- **data_dir** (*str*, *optional*) – The directory of the dataset. If none exists, a new dataset will be downloaded and saved to this path. If None, the directory defaults to your home directory, by default None.

Returns *pandas.DataFrame* – Table with correlation values for each feature.

brainstat.context.resting

Functions

<code>gradients_corr(data[, name, template, ...])</code>	Computes the correlation of the input data with the Margulies gradients.
<code>yeo_networks_associations(data[, template, ...])</code>	Computes association

brainstat.context.resting.gradients_corr

```
brainstat.context.resting.gradients_corr(data, name='margulies2016', template='fsaverage5', data_dir=None, overwrite=False)
```

Computes the correlation of the input data with the Margulies gradients.

Parameters

- **data** (*ArrayLike*) – The data to be compared to the Margulies gradients. Data must be in the shape of vertices-by-features.
- **name** (*str*, *optional*) – Name of the gradients. Valid values are “margulies2016”, defaults to “margulies2016”.
- **template** (*str*, *optional*) – Name of the template surface. Valid values are “fsaverage5”, “fsaverage7”, “fslr32k”, defaults to “fsaverage5”.
- **data_dir** (*str*, *Path*, *optional*) – Path to the directory to store the Margulies gradient data files, by default \$HOME_DIR/brainstat_data/functional_data.
- **overwrite** (*bool*, *optional*) – If true, overwrites existing files, by default False.

Returns *np.ndarray* – Correlations between the input data and the Margulies gradients.

brainstat.context.resting.yeo_networks_associations

```
brainstat.context.resting.yeo_networks_associations(data, template='fsaverage5', seven_networks=True, data_dir=None, reduction_operation=<function nanmean>)
```

Computes association

Parameters

- **data** (*ArrayLike*) – Data to be summarized in the Yeo networks in a sample-by-feature format.

- **template** (*str*, *optional*) – Surface template. Valid values are “fsaverage5”, “fsaverage”, and “fslr32k”, “civet41k”, and “civet164k”, by default “fsaverage5”.
- **seven_networks** (*bool*, *optional*) – If true, uses the 7 network parcellation, otherwise uses the 17 network parcellation, by default True.
- **data_dir** (*str*, *Path*, *optional*) – Data directory to store the Yeo network files, by default \$HOME_DIR/brainstat_data/parcellation_data.
- **reduction_operation** (*str*, *callable*, *optional*) – How to summarize data. If str, options are: {‘min’, ‘max’, ‘sum’, ‘mean’, ‘median’, ‘mode’, ‘average’}. If callable, it should receive a 1D array of values, array of weights (or None) and return a scalar value. Default is ‘mean’.

Returns *np.ndarray* – Summary statistic in the yeo networks.

brainstat.datasets

Data included with BrainStat.

Modules

<i>brainstat.datasets.base</i>	Load external datasets.
--------------------------------	-------------------------

brainstat.datasets.base

Load external datasets.

Functions

<i>fetch_gradients</i> ([template, name, data_dir, ...])	Fetch example gradients.
<i>fetch_mask</i> (template[, join, data_dir, overwrite])	Fetches midline masks.
<i>fetch_parcellation</i> (template, atlas, n_regions)	Loads the surface parcellation of a given atlas.
<i>fetch_template_surface</i> (template[, join, ...])	Loads surface templates.
<i>fetch_yeo_networks_metadata</i> (n)	Fetch Yeo networks metadata.

brainstat.datasets.base.fetch_gradients

`brainstat.datasets.base.fetch_gradients` (*template*=‘fsaverage5’, *name*=‘margulies2016’, *data_dir*=None, *overwrite*=False)

Fetch example gradients.

Parameters

- **template** (*str*, *optional*) – Name of the template surface. Valid values are “fsaverage5”, “fsaverage”, “fslr32k”, defaults to “fsaverage5”.
- **name** (*str*) – Name of the gradients. Valid values are “margulies2016”, defaults to “margulies2016”.
- **data_dir** (*str*, *Path*, *optional*) – Path to the directory to store the gradient data files, by default \$HOME_DIR/brainstat_data/gradient_data.

- **overwrite** (*bool*, *optional*) – If true, overwrites existing files, by default False.

Returns *numpy.ndarray* – Vertex-by-gradient matrix.

brainstat.datasets.base.fetch_mask

`brainstat.datasets.base.fetch_mask(template, join=True, data_dir=None, overwrite=False)`

Fetches midline masks.

Parameters

- **template** (*str*) – Name of the surface template. Valid templates are: “fsaverage5”, “fsaverage”, “fslr32k”, “civet41k”, and “civet164k”.
- **join** (*bool*, *optional*) – If true, returns a numpy array containing the mask. If false, returns a tuple containing the left and right hemispheric masks, respectively, by default True
- **data_dir** (*str*, *pathlib.Path*, *optional*) – Directory to save the data, by default \$HOME_DIR/brainstat_data/surface_data.

Returns *numpy.ndarray* or *tuple of numpy.ndarray* – Midline mask, either as a single array or a tuple of a left and right hemispheric array.

brainstat.datasets.base.fetch_parcellation

`brainstat.datasets.base.fetch_parcellation(template, atlas, n_regions, join=True, seven_networks=True, data_dir=None)`

Loads the surface parcellation of a given atlas.

Parameters

- **template** (*str*,) – The surface template. Valid values are “fsaverage”, “fsaverage5”, “fsaverage6”, “fslr32k”, “civet41k”, “civet164k”, by default “fsaverage5”.
- **atlas** (*str*) – Name of the atlas. Valid names are “cammoun”, “glasser”, “schaefer”, “yeo”.
- **n_regions** (*int*) – Number of regions of the requested atlas. Valid values for the cammoun atlas are 33, 60, 125, 250, 500. Valid values for the glasser atlas are 360. Valid values for the “schaefer” atlas are 100, 200, 300, 400, 500, 600, 800, 1000. Valid values for “yeo” are 7 and 17.
- **join** (*bool*, *optional*) – If true, returns parcellation as a single array, if false, returns an array per hemisphere, by default True.
- **seven_networks** (*bool*, *optional*) – If true, uses the 7 networks parcellation. Only used for the Schaefer atlas, by default True.
- **data_dir** (*str*, *pathlib.Path*, *optional*) – Directory to save the data, defaults to \$HOME_DIR/brainstat_data/parcellation_data.

Returns *np.ndarray* or *tuple of np.ndarray* – Surface parcellation. If a tuple, then the first element is the left hemisphere.

brainstat.datasets.base.fetch_template_surface

`brainstat.datasets.base.fetch_template_surface(template, join=True, layer=None, data_dir=None)`

Loads surface templates.

Parameters

- **template** (*str*) – Name of the surface template. Valid values are “fslr32k”, “fsaverage”, “fsaverage3”, “fsaverage4”, “fsaverage5”, “fsaverage6”, “civet41k”, “civet164k”.
- **join** (*bool, optional*) – If true, returns surfaces as a single object, if false, returns an object per hemisphere, by default True.
- **layer** (*str, optional*) – Name of the cortical surface of interest. Valid values are “white”, “smoothwm”, “pial”, “inflated”, “sphere” for fsaverage surfaces; “midthickness”, “inflated”, “vinflated” for “fslr32k”; “mid”, “white” for CIVET surfaces; and “sphere” for “civet41k”. If None, defaults to “pial” or “midthickness”, by default None.
- **data_dir** (*str, Path, optional*) – Directory to save the data, by default \$HOME_DIR/brainstat_data/surface_data.

Returns *BSPolyData or tuple of BSPolyData* – Output surface(s). If a tuple, then the first element is the left hemisphere.

brainstat.datasets.base.fetch_yeo_networks_metadata

`brainstat.datasets.base.fetch_yeo_networks_metadata(n)`

Fetch Yeo networks metadata.

Parameters **n** (*int*) – Number of Yeo networks, either 7 or 17.

Returns

- *list of str* – Names of Yeo networks.
- *np.ndarray* – Colormap for the Yeo networks.

brainstat.mesh

Module for the handling of meshes and mesh data.

Modules

<code>brainstat.mesh.data</code>	Operations on data on a mesh.
<code>brainstat.mesh.interpolate</code>	Interpolations on a mesh.
<code>brainstat.mesh.utils</code>	Operations on meshes.

brainstat.mesh.data

Operations on data on a mesh.

Functions

<code>mesh_smooth(Y, surf, FWHM)</code>	Smooths surface data by repeatedly averaging over edges.
---	--

brainstat.mesh.data.mesh_smooth

`brainstat.mesh.data.mesh_smooth(Y, surf, FWHM)`
Smooths surface data by repeatedly averaging over edges.

Parameters

- **Y** (*numpy.ndarray*) – Surface data of shape (n,v) or (n,v,k). v is the number of vertices, n is the number of observations, k is the number of variates.
- **surf** (*dict*, *BSPolyData*) – A dictionary with key ‘tri’ or ‘lat’, or a BSPolyData object of the surface. surf[‘tri’] is a *numpy.ndarray* of shape (t,3), t is the triangle indices, or surf[‘lat’] is a *numpy.ndarray* of shape (nx,ny,nz), where (nx,ny,nz) is the volume size, values are 1=in, 0=out.
- **FWHM** (*float*) – Gaussian smoothing filter in mesh units.

Returns *numpy.ndarray* – Smoothed surface data of shape (n,v) or (n,v,k).

brainstat.mesh.interpolate

Interpolations on a mesh.

Functions

<code>combine_parcellations(files, output_file)</code>	Combines multiple nifti files into one.
<code>cortical_ribbon(pial_mesh, wm_mesh, nii[, ...])</code>	Finds voxels inside of the cortical ribbon.
<code>load_mesh_labels(label_file[, as_int])</code>	Loads a .label.gii or .csv file.
<code>multi_surface_to_volume(pial, white, ...[, ...])</code>	Interpolates multiple surfaces to the volume.
<code>read_surface_gz(filename)</code>	Extension of brainspace’s read_surface to include .gz files.
<code>ribbon_interpolation(pial_mesh, wm_mesh, ...)</code>	Performs label interpolation in the cortical ribbon.
<code>surface_to_volume(pial_mesh, wm_mesh, ...[, ...])</code>	Projects surface labels to the cortical ribbon.

brainstat.mesh.interpolate.combine_parcellations

`brainstat.mesh.interpolate.combine_parcellations` (*files*, *output_file*)

Combines multiple nifti files into one.

Parameters

- **files** (*list*) – List of strings containing the paths to nifti files.
- **output_file** (*str*) – Path to the output file.

Notes

This function assumes that 0's are missing data. When multiple files have non-zero values in the same voxel, then the data from the first provided file is kept.

brainstat.mesh.interpolate.cortical_ribbon

`brainstat.mesh.interpolate.cortical_ribbon` (*pial_mesh*, *wm_mesh*, *nii*, *mesh_distance=6*)

Finds voxels inside of the cortical ribbon.

Parameters

- **pial_mesh** (*BSPolyData*) – Pial mesh.
- **wm_mesh** (*BSPolyData*) – White matter mesh.
- **nii** (*Nibabel nifti*) – Nifti image containing the space in which to output the ribbon.
- **mesh_distance** (*float*, *optional*) – Maximum distance from the cortical mesh at which the ribbon may occur. Used to reduce the search space, by default 6.

Returns *numpy.ndarray* – Matrix coordinates of voxels inside the cortical ribbon.

brainstat.mesh.interpolate.load_mesh_labels

`brainstat.mesh.interpolate.load_mesh_labels` (*label_file*, *as_int=True*)

Loads a .label.gii or .csv file.

Parameters

- **label_file** (*str*) – Path to the label file.
- **as_int** (*bool*) – Determines whether to enforce integer format on the labels, defaults to True.

Returns *numpy.ndarray* – Labels in the file.

brainstat.mesh.interpolate.multi_surface_to_volume

`brainstat.mesh.interpolate.multi_surface_to_volume` (*pial*, *white*, *volume_template*, *output_file*, *labels*, *interpolation*='nearest')

Interpolates multiple surfaces to the volume.

Parameters

- **pial** (*str*, *BSPolyData*, *list*, *tuple*) – Path of a pial surface file, *BSPolyData* of a pial surface or a list containing multiple of the aforementioned.
- **white** (*str*, *BSPolyData*, *list*, *tuple*) – Path of a white matter surface file, *BSPolyData* of a pial surface or a list containing multiple of the aforementioned.
- **volume_template** (*str*, *nibabel.nifti1.Nifti1Image*) – Path to a nifti file to use as a template for the surface to volume procedure, or a loaded NIfTI image.
- **output_file** (*str*) – Path to the output file, must end in .nii or .nii.gz.
- **labels** (*str*, *numpy.ndarray*, *list*, *tuple*) – Path to a label file for the surfaces, numpy array containing the labels, or a list containing multiple of the aforementioned.
- **interpolation** (*str*) – Either 'nearest' for nearest neighbor interpolation, or 'linear' for trilinear interpolation, defaults to 'nearest'.

Notes

An equal number of pial/white surfaces and labels must be provided. If parcellations overlap across surfaces, then the labels are kept for the first provided surface.

brainstat.mesh.interpolate.read_surface_gz

`brainstat.mesh.interpolate.read_surface_gz` (*filename*)

Extension of brainspace's `read_surface` to include .gz files.

Parameters *filename* (*str*) – Filename of file to open.

Returns *BSPolyData* – Surface mesh.

brainstat.mesh.interpolate.ribbon_interpolation

`brainstat.mesh.interpolate.ribbon_interpolation` (*pial_mesh*, *wm_mesh*, *labels*, *nii*, *points*, *interpolation*='nearest')

Performs label interpolation in the cortical ribbon.

Parameters

- **pial_mesh** (*BSPolyData*) – Pial mesh.
- **wm_mesh** (*BSPolydata*) – White matter mesh.
- **labels** (*str*, *numpy.ndarray*) – Filename of a .label.gii or .shape.gii file, or a numpy array containing the labels.
- **nii** (*Nibabel nifti*) – Reference nifti image.
- **points** (*numpy.array*) – Numpy array containing the coordinates of the ribbon.

- **interpolation** (*str*, *optional*) – Interpolation method. Can be either ‘nearest’ or ‘linear’.

Returns *numpy.ndarray* – Interpolated value for each input point.

Notes

Strictly, this function will work outside the cortical ribbon too and assign any point to its label on the nearest mesh. An adventurous user could use this for nearest neighbour surface to volume anywhere in the brain, although such usage is not officially supported.

brainstat.mesh.interpolate.surface_to_volume

`brainstat.mesh.interpolate.surface_to_volume(pial_mesh, wm_mesh, labels, volume_template, volume_save, interpolation='nearest')`

Projects surface labels to the cortical ribbon.

Parameters

- **pial_mesh** (*str*, *BSPolyData*) – Filename of a pial mesh or a *BSPolyData* object of the same.
- **wm_mesh** (*str*, *BSPolyData*) – Filename of a pial mesh or a *BSPolyData* object of the same.
- **labels** (*str*, *numpy.ndarray*) – Filename of a .label.gii or .shape.gii file, or a numpy array containing the labels.
- **volume_template** (*str*, *nibabel.nifti1.Nifti1Image*) – Filename of a nifti image in the same space as the mesh files or a NIFTI image loaded with nibabel.
- **volume_save** (*str*) – Filename to which the label image will be saved.
- **interpolation** (*str*) – Either ‘nearest’ for nearest neighbor interpolation, or ‘linear’ for trilinear interpolation, defaults to ‘nearest’.

brainstat.mesh.utils

Operations on meshes.

Functions

<code>mesh_edges(surf[, mask])</code>	Converts the triangles or lattices of a mesh to edges.
---------------------------------------	--

brainstat.mesh.utils.mesh_edges

brainstat.mesh.utils.**mesh_edges** (*surf*, *mask=None*)

Converts the triangles or lattices of a mesh to edges.

Args: *surf* (dict): = a dictionary with key 'tri' or 'lat' *surf*['tri'] = (t x 3) numpy array of triangle indices, t:#triangles, or, *surf*['lat'] = 3D numpy array of 1's and 0's (1:in, 0:out). or *surf* (BSPolyData) = a BrainSpace surface object or *surf* (SLM) = a SLM object with an associated surface.

Returns: *edg* (np.array): A e-by-2 numpy array containing the indices of the edges, where e is the number of edges.

brainstat.stats

The statistics tools of BrainStat

Modules

<code>brainstat.stats.SLM</code>	Standard Linear regression models.
<code>brainstat.stats.terms</code>	Classes for fixed, mixed, and random effects.
<code>brainstat.stats.utils</code>	Utilities for the stats functions.

brainstat.stats.SLM

Standard Linear regression models.

Functions

<code>f_test</code> (<i>slm1</i> , <i>slm2</i>)	F-statistics for comparing two uni- or multi-variate fixed effects models.
---	--

brainstat.stats.SLM.f_test

brainstat.stats.SLM.**f_test** (*slm1*, *slm2*)

F-statistics for comparing two uni- or multi-variate fixed effects models.

Parameters

- **slm1** (`brainstat.stats.SLM.SLM`) – Standard linear model returned by the `t_test` function; see Notes for details.
- **slm2** (`brainstat.stats.SLM.SLM`) – Standard linear model returned by the `t_test` function; see Notes for details.

Returns `brainstat.stats.SLM.SLM` – Standard linear model with f-test results included.

Classes

<code>SLM(model, contrast[, surf, mask, ...])</code>	Core Class for running BrainStat linear models
--	--

brainstat.stats.SLM.SLM

```
class brainstat.stats.SLM.SLM(model, contrast, surf=None, mask=None, *, correction=None,  
                             niter=1, thetalim=0.01, drlim=0.1, two_tailed=True, cluster_threshold=0.001, data_dir=None)
```

Bases: `object`

Core Class for running BrainStat linear models

```
__init__(model, contrast, surf=None, mask=None, *, correction=None, niter=1, thetalim=0.01, drlim=0.1, two_tailed=True, cluster_threshold=0.001, data_dir=None)
```

Constructor for the SLM class.

Parameters

- **model** (`brainstat.stats.terms.FixedEffect`, `brainstat.stats.terms.MixedEffect`) – The linear model to be fitted of dimensions (observations, predictors).
- **contrast** (*array-like*) – Vector of contrasts in the observations.
- **surf** (*str, dict, BSPolyData, optional*) – A surface provided as either a dictionary with keys ‘tri’ for its faces (n-by-3 array) and ‘coord’ for its coordinates (3-by-n array), or as a BrainSpace BSPolyData object, or a string containing a template name accepted by `fetch_template_surface`, by default `None`.
- **mask** (*array-like, optional*) – A mask containing True for vertices to include in the analysis, by default `None`.
- **correction** (*str, Sequence, optional*) – String or sequence of strings. If it contains “rft” a random field theory multiple comparisons correction will be run. If it contains “fdr” a false discovery rate multiple comparisons correction will be run. Both may be provided. By default `None`.
- **niter** (*int, optional*) – Number of iterations of the Fisher scoring algorithm for fitting mixed effects models, by default 1.
- **thetalim** (*float, optional*) – Lower limit on variance coefficients in standard deviations, by default 0.01.
- **drlim** (*float, optional*) – Step of ratio of variance coefficients in standard deviations, by default 0.1.
- **two_tailed** (*bool, optional*) – Determines whether to return two-tailed or one-tailed p-values. Note that multivariate analyses can only be two-tailed, by default `True`.
- **cluster_threshold** (*float, optional*) – P-value threshold or statistic threshold for defining clusters in random field theory, by default 0.001.
- **data_dir** (*str, pathlib.Path, optional*) – Path to the location to store BrainStat data files, defaults to `$HOME_DIR/brainstat_data`.

Methods

<code>__init__(model, contrast[, surf, mask, ...])</code>	Constructor for the SLM class.
<code>fdr(**kwargs)</code>	
<code>fit(Y)</code>	Fits the SLM model
<code>linear_model(**kwargs)</code>	
<code>multiple_comparison_corrections(student_t_test)</code>	Performs multiple comparisons corrections.
<code>random_field_theory(**kwargs)</code>	
<code>t_test(**kwargs)</code>	

Attributes

<code>lat</code>
<code>surf</code>
<code>tri</code>

fit (*Y*)

Fits the SLM model

Parameters *Y* (*numpy.array*) – Input data (observation, vertex, variate)

Raises **ValueError** – An error will be thrown when multivariate data is provided and a one-tailed test is requested.

multiple_comparison_corrections (*student_t_test*)

Performs multiple comparisons corrections. If a (one-sided) student-t test was run, then make it two-tailed if requested.

brainstat.stats.terms

Classes for fixed, mixed, and random effects.

Functions

<code>check_duplicate_names(df1[, df2])</code>	Check columns with duplicate names.
<code>check_names(x)</code>	Return True if <i>x</i> is FixedEffect, Series or DataFrame.
<code>get_index(df)</code>	Get index for column names of the form x{i}.
<code>remove_duplicate_columns(df[, tol])</code>	Remove duplicate columns.
<code>remove_identical_columns(df1, df2)</code>	Remove columns with duplicate names across dataframes.
<code>to_df(x[, n, names, idx])</code>	Convert input to DataFrame.

brainstat.stats.terms.check_duplicate_names

`brainstat.stats.terms.check_duplicate_names(df1, df2=None)`

Check columns with duplicate names.

Parameters

- **df1** (*DataFrame*) – Input dataframe.
- **df2** (*DataFrame, optional*) – If provided, check that dataframes do not contain columns with same names. Default is None.

Raises **ValueError** – If there are columns with duplicate names.

brainstat.stats.terms.check_names

`brainstat.stats.terms.check_names(x)`

Return True if *x* is FixedEffect, Series or DataFrame.

brainstat.stats.terms.get_index

`brainstat.stats.terms.get_index(df)`

Get index for column names of the form *x*{*i*}.

If there are none, return 0.

Parameters **df** (*DataFrame*) – Input dataframe.

Returns **index** (*int*) – Index for the next *x* column. If *df* is empty, return None.

brainstat.stats.terms.remove_duplicate_columns

`brainstat.stats.terms.remove_duplicate_columns(df, tol=1e-08)`

Remove duplicate columns.

Parameters

- **df** (*DataFrame*) – Input dataframe.
- **tol** (*float, optional*) – Tolerance to assess duplicate columns. Default is 1e-8.

Returns **columns** (*list of str*) – Columns to keep after removing duplicates.

brainstat.stats.terms.remove_identical_columns

`brainstat.stats.terms.remove_identical_columns(df1, df2)`

Remove columns with duplicate names across dataframes.

Parameters

- **df1** (*DataFrame*) – Input dataframe from which to drop columns.
- **df2** (*DataFrame*) – Reference dataframe

Returns *DataFrame* – *df1* with columns appearing in *df2* removed.

Raises **ValueError** – If there are columns with duplicate names but no duplicate values.

brainstat.stats.terms.to_df

`brainstat.stats.terms.to_df(x, n=1, names=None, idx=None)`

Convert input to DataFrame.

Parameters

- **x** (*int*, *array-like FixedEffect*) – Input data.
- **n** (*int*, *optional*) – If input is a scalar, broadcast to column of *n* entries. Default is 1.
- **names** (*str*, *sequence of str or None, optional*) – Names for each column in *x*. Default is None.
- **idx** (*int or None, optional*) – Starting index for variable names of the for $x\{i\}$.

Returns **df** (*DataFrame*) – Input *x* wrapped in a DataFrame.

Classes

<code>FixedEffect([x, names, add_intercept])</code>	Build a term object for a linear model.
<code>MixedEffect([ran, fix, name_ran, name_fix, ...])</code>	Build a random term object for a linear model.

brainstat.stats.terms.FixedEffect

class `brainstat.stats.terms.FixedEffect` (*x=None, names=None, add_intercept=True*)

Bases: `object`

Build a term object for a linear model.

Parameters

- **x** (*array-like or DataFrame, optional*) – If None, the term is empty. Default is None.
- **names** (*str or list of str, optional*) – Names for each column in *x*. If None, it defaults to `{‘x0’, ‘x1’, ... }`. Default is None.
- **add_intercept** (*bool, optional*) – If true, adds an intercept term. Defaults to True.

Variables

- **x** (*DataFrame*) – Design matrix.
- **names** (*list of str*) – Names of columns in the design matrix.

See also:

`MixedEffect` MixedEffect term

Examples

```
>>> t = FixedEffect()
>>> t.is_empty
True
```

```
>>> t1 = FixedEffect(np.arange(5), names='t1')
>>> t2 = FixedEffect(np.random.randn(5, 1), names=['t2'])
>>> t3 = t1 + t2
>>> t3.shape
(5, 3)
```

__init__(x=None, names=None, add_intercept=True)
Initialize self. See help(type(self)) for accurate signature.

Methods

__init__([x, names, add_intercept])	Initialize self.
-------------------------------------	------------------

Attributes

is_empty

is_scalar

matrix

names

tolerance

brainstat.stats.terms.MixedEffect

```
class brainstat.stats.terms.MixedEffect (ran=None,      fix=None,      name_ran=None,
                                         name_fix=None,      ranisvar=False,
                                         add_intercept=True, add_identity=True)
```

Bases: `object`

Build a random term object for a linear model.

Parameters

- **ran** (*array-like or DataFrame, optional*) – For the random effects. If None, the random term is empty. Default is None.
- **fix** (*array-like or DataFrame, optional*) – If None, the fixed effects.
- **name_ran** (*str, list, optional*) – Name(s) for the random term(s). If None, it defaults to 'xi'. Default is None.
- **name_fix** (*str, optional*) – Name for the *fix* term. If None, it defaults to 'xi'. Default

is None.

- **ranisvar** (*bool*, *optional*) – If True, *ran* is already a term for the variance. Default is False.

Variables

- **mean** (*FixedEffect*) – FixedEffect for the mean.
- **variance** (*FixedEffect*) – FixedEffect for the variance.

See also:

FixedEffect FixedEffect object

Examples

```
>>> r = MixedEffect()
>>> r.is_empty
True
```

```
>>> r2 = MixedEffect(np.arange(5), name_ran='r1')
>>> r2.mean.is_empty
True
>>> r2.variance.shape
(25, 2)
```

__init__ (*ran=None*, *fix=None*, *name_ran=None*, *name_fix=None*, *ranisvar=False*, *add_intercept=True*, *add_identity=True*)
Initialize self. See help(type(self)) for accurate signature.

Methods

<code>__init__</code> ([<i>ran</i> , <i>fix</i> , <i>name_ran</i> , <i>name_fix</i> , ...])	Initialize self.
<code>broadcast_to</code> (<i>r1</i> , <i>r2</i>)	
<code>set_identity_last</code> ()	Sets the identity matrix column last.

Attributes

<code>empty</code>
<code>shape</code>

set_identity_last ()
Sets the identity matrix column last.

Raises **ValueError** – Raised if “I” occurs more than once in the names.

brainstat.stats.utils

Utilities for the stats functions.

Functions

<code>apply_mask(Y, mask[, axis])</code>	Masks the data along a specified axis
<code>colon(start, stop[, increment])</code>	Generates a range of numbers including the stop number.
<code>interp1(x, y, ix[, kind])</code>	Interpolation between datapoints.
<code>ismember(A, B[, rows])</code>	Tests whether elements of A appear in B.
<code>row_ismember(a, b)</code>	Tests whether rows of a occur in b.
<code>undo_mask(Y, mask[, axis, missing_value])</code>	Restores the original dimensions of masked data.

brainstat.stats.utils.apply_mask

`brainstat.stats.utils.apply_mask(Y, mask, axis=0)`

Masks the data along a specified axis

Parameters

- **Y** (*numpy.ndarray*) – Data to be masked.
- **mask** (*numpy.ndarray*) – Boolean vector containing True for each element to keep.
- **axis** (*int*, *optional*) – Axis along which to operate, by default 0.

Returns *numpy.ndarray* – Masked data.

brainstat.stats.utils.colon

`brainstat.stats.utils.colon(start, stop, increment=1)`

Generates a range of numbers including the stop number.

Parameters

- **start** (*float*) – Starting number of the range.
- **stop** (*float*) – Stopping number of the range.
- **increment** (*float*, *optional*) – Increments of the range, defaults to 1.

Returns *numpy.array* – The requested numbers.

brainstat.stats.utils.interp1

`brainstat.stats.utils.interp1(x, y, ix, kind='linear')`

Interpolation between datapoints.

Parameters

- **x** (*ArrayLike*) – x coordinates of training data.
- **y** (*ArrayLike*) – y coordinates of training data.

- **ix** (*ArrayLike*) – coordinates of the interpolated points.
- **str** (*kind*) – type of interpolation; see `scipy.interpolate.interp1d` for options.
- **int** – type of interpolation; see `scipy.interpolate.interp1d` for options.
- **optional** – type of interpolation; see `scipy.interpolate.interp1d` for options.

Returns *numpy.array* – interpolated y coordinates.

brainstat.stats.utils.ismember

`brainstat.stats.utils.ismember(A, B, rows=False)`

Tests whether elements of A appear in B.

Parameters

- **A** (*numpy.ndarray*) – 1D or 2D array
- **B** (*numpy.ndarray*) – 1D or 2D array
- **rows** (*bool, optional*) – If true test for row correspondence rather than element correspondence.

Returns

- *bool* – Boolean of the same size as A denoting which elements (or rows) occur in B.
- *numpy.ndarray* – Indices of matching elements/rows in A.

Notes

For row-wise comparisons, `row_ismember` should be significantly faster.

brainstat.stats.utils.row_ismember

`brainstat.stats.utils.row_ismember(a, b)`

Tests whether rows of a occur in b.

Parameters

- **a** (*numpy.array*) – a 2D array with the same number of columns as b.
- **b** (*numpy.array*) – a 2D array with the same number of columns as a.

Returns *list* – Indices of rows in a that occur in b.

brainstat.stats.utils.undo_mask

`brainstat.stats.utils.undo_mask(Y, mask, axis=0, missing_value=nan)`

Restores the original dimensions of masked data.

Parameters

- **Y** (*numpy.ndarray*) – Masked data.
- **mask** (*numpy.ndarray*) – Boolean vector used to mask the data.
- **axis** (*int, optional*) – Axis along which to operate, by default 0.

- **missing_value** (*scalar, optional*) – Number to insert for missing values, by default np.nan.

Returns *numpy.ndarray* – Unmasked data.

brainstat.tests

Unit tests and their data generation.

Modules

<code>brainstat.tests.datagen_f</code>	Data generation for f-test unit tests.
<code>brainstat.tests.datagen_linear_model</code>	Data generation for linear model unit tests.
<code>brainstat.tests.datagen_mesh_edges</code>	Data generation for mesh_edges unit tests.
<code>brainstat.tests.datagen_peak_clus</code>	Data generation for peak_clus unit tests.
<code>brainstat.tests.datagen_stat_threshold</code>	Data generation for stat_threshold unit tests.
<code>brainstat.tests.datagen_t_test</code>	Data generation for t-test unit tests.
<code>brainstat.tests.test_f_test</code>	Unit tests of f-test.
<code>brainstat.tests.test_mesh_edges</code>	Unit tests of mesh_edges.
<code>brainstat.tests.test_mesh_smooth</code>	Unit tests of mesh_smooth.
<code>brainstat.tests.test_stat_threshold</code>	Unit tests of stat_threshold.
<code>brainstat.tests.test_terms</code>	Tests the fixed and mixed effects classes.
<code>brainstat.tests.testutil</code>	Utilities for running tests and test data generation.

brainstat.tests.datagen_f

Data generation for f-test unit tests.

Functions

<code>generate_f_test_out(slm1, slm2)</code>	
<code>generate_random_two_slms(I)</code>	
<code>generate_test_data()</code>	
<code>params2files(I, D, test_num)</code>	Converts params to input/output files

brainstat.tests.datagen_f.generate_f_test_out

`brainstat.tests.datagen_f.generate_f_test_out(slm1, slm2)`

brainstat.tests.datagen_f.generate_random_two_slms

`brainstat.tests.datagen_f.generate_random_two_slms(I)`

brainstat.tests.datagen_f.generate_test_data

`brainstat.tests.datagen_f.generate_test_data()`

brainstat.tests.datagen_f.params2files

`brainstat.tests.datagen_f.params2files(I, D, test_num)`
Converts params to input/output files

brainstat.tests.datagen_linear_model

Data generation for linear model unit tests.

Functions

`generate_test_data()`

brainstat.tests.datagen_linear_model.generate_test_data

`brainstat.tests.datagen_linear_model.generate_test_data()`

brainstat.tests.datagen_mesh_edges

Data generation for mesh_edges unit tests.

Functions

`generate_data_test_mesh_edges()`

`generate_random_mesh_edge_data(key_dim, finname)` Generate random test datasets.

`get_meshedge_output(surf, foutname)` Runs mesh_edges and returns all relevant output.

brainstat.tests.datagen_mesh_edges.generate_data_test_mesh_edges

```
brainstat.tests.datagen_mesh_edges.generate_data_test_mesh_edges()
```

brainstat.tests.datagen_mesh_edges.generate_random_mesh_edge_data

```
brainstat.tests.datagen_mesh_edges.generate_random_mesh_edge_data(key_dim,
                                                                    finname,
                                                                    key_name='tri',
                                                                    key_dtype='float',
                                                                    seed=0)
```

Generate random test datasets.

brainstat.tests.datagen_mesh_edges.get_meshedge_output

```
brainstat.tests.datagen_mesh_edges.get_meshedge_output(surf, foutname)
```

Runs mesh_edges and returns all relevant output.

brainstat.tests.datagen_peak_clus

Data generation for peak_clus unit tests.

Functions

```
generate_peak_clus_out(slm, I)
```

```
generate_random_slm(I)
```

```
generate_test_data()
```

```
params2files(I, D, test_num) Converts params to input/output files
```

brainstat.tests.datagen_peak_clus.generate_peak_clus_out

```
brainstat.tests.datagen_peak_clus.generate_peak_clus_out(slm, I)
```

brainstat.tests.datagen_peak_clus.generate_random_slm

`brainstat.tests.datagen_peak_clus.generate_random_slm(I)`

brainstat.tests.datagen_peak_clus.generate_test_data

`brainstat.tests.datagen_peak_clus.generate_test_data()`

brainstat.tests.datagen_peak_clus.params2files

`brainstat.tests.datagen_peak_clus.params2files(I, D, test_num)`
Converts params to input/output files

brainstat.tests.datagen_stat_threshold

Data generation for stat_threshold unit tests.

Functions

`generate_stat_threshold_out(I)`

`generate_test_data()`

`params2files(I, D, test_num)` Converts params to input/output files

brainstat.tests.datagen_stat_threshold.generate_stat_threshold_out

`brainstat.tests.datagen_stat_threshold.generate_stat_threshold_out(I)`

brainstat.tests.datagen_stat_threshold.generate_test_data

`brainstat.tests.datagen_stat_threshold.generate_test_data()`

brainstat.tests.datagen_stat_threshold.params2files

`brainstat.tests.datagen_stat_threshold.params2files(I, D, test_num)`
 Converts params to input/output files

brainstat.tests.datagen_t_test

Data generation for t-test unit tests.

Functions

`generate_test_data()`

brainstat.tests.datagen_t_test.generate_test_data

`brainstat.tests.datagen_t_test.generate_test_data()`

brainstat.tests.test_f_test

Unit tests of f-test.

Functions

`dummy_test(infile, expfile)`

`test_01()`

`test_02()`

`test_03()`

`test_04()`

`test_05()`

`test_06()`

`test_07()`

`test_08()`

`test_09()`

`test_10()`

continues on next page

Table 32 – continued from previous page

`test_11()`

`test_12()`

`test_13()`

`test_14()`

`test_15()`

`test_16()`

brainstat.tests.test_f_test.dummy_test`brainstat.tests.test_f_test.dummy_test (infile, expfile)`**brainstat.tests.test_f_test.test_01**`brainstat.tests.test_f_test.test_01()`**brainstat.tests.test_f_test.test_02**`brainstat.tests.test_f_test.test_02()`**brainstat.tests.test_f_test.test_03**`brainstat.tests.test_f_test.test_03()`**brainstat.tests.test_f_test.test_04**`brainstat.tests.test_f_test.test_04()`**brainstat.tests.test_f_test.test_05**`brainstat.tests.test_f_test.test_05()`

brainstat.tests.test_f_test.test_06

```
brainstat.tests.test_f_test.test_06()
```

brainstat.tests.test_f_test.test_07

```
brainstat.tests.test_f_test.test_07()
```

brainstat.tests.test_f_test.test_08

```
brainstat.tests.test_f_test.test_08()
```

brainstat.tests.test_f_test.test_09

```
brainstat.tests.test_f_test.test_09()
```

brainstat.tests.test_f_test.test_10

```
brainstat.tests.test_f_test.test_10()
```

brainstat.tests.test_f_test.test_11

```
brainstat.tests.test_f_test.test_11()
```

brainstat.tests.test_f_test.test_12

```
brainstat.tests.test_f_test.test_12()
```

brainstat.tests.test_f_test.test_13

```
brainstat.tests.test_f_test.test_13()
```

brainstat.tests.test_f_test.test_14

```
brainstat.tests.test_f_test.test_14()
```

brainstat.tests.test_f_test.test_15

`brainstat.tests.test_f_test.test_15()`

brainstat.tests.test_f_test.test_16

`brainstat.tests.test_f_test.test_16()`

brainstat.tests.test_mesh_edges

Unit tests of mesh_edges.

Functions

dummy_test(infile, expfile)

test_01()

test_02()

test_03()

test_04()

brainstat.tests.test_mesh_edges.dummy_test

`brainstat.tests.test_mesh_edges.dummy_test (infile, expfile)`

brainstat.tests.test_mesh_edges.test_01

`brainstat.tests.test_mesh_edges.test_01()`

brainstat.tests.test_mesh_edges.test_02

```
brainstat.tests.test_mesh_edges.test_02()
```

brainstat.tests.test_mesh_edges.test_03

```
brainstat.tests.test_mesh_edges.test_03()
```

brainstat.tests.test_mesh_edges.test_04

```
brainstat.tests.test_mesh_edges.test_04()
```

brainstat.tests.test_mesh_smooth

Unit tests of mesh_smooth.

Functions

```
dummy_test(infile, expfile)
```

```
test_01()
```

brainstat.tests.test_mesh_smooth.dummy_test

```
brainstat.tests.test_mesh_smooth.dummy_test(infile, expfile)
```

brainstat.tests.test_mesh_smooth.test_01

```
brainstat.tests.test_mesh_smooth.test_01()
```

brainstat.tests.test_stat_threshold

Unit tests of stat_threshold.

Functions

```
dummy_test(infile, expfile)
```

```
test_01()
```

```
test_02()
```

continues on next page

Table 35 – continued from previous page

<i>test_03()</i>
<i>test_04()</i>
<i>test_05()</i>
<i>test_06()</i>
<i>test_07()</i>
<i>test_08()</i>
<i>test_09()</i>
<i>test_10()</i>
<i>test_11()</i>
<i>test_12()</i>
<i>test_13()</i>
<i>test_14()</i>
<i>test_15()</i>
<i>test_16()</i>
<i>test_17()</i>
<i>test_18()</i>
<i>test_19()</i>
<i>test_20()</i>
<i>test_21()</i>
<i>test_22()</i>
<i>test_23()</i>
<i>test_24()</i>
<i>test_25()</i>
<i>test_26()</i>
<i>test_27()</i>

continues on next page

Table 35 – continued from previous page

test_28()

test_29()

test_30()

test_31()

test_32()

test_33()

test_34()

test_35()

test_36()

test_37()

test_38()

test_39()

test_40()

test_41()

test_42()

test_43()

test_44()

test_45()

test_46()

test_47()

test_48()

brainstat.tests.test_stat_threshold.dummy_test

`brainstat.tests.test_stat_threshold.dummy_test` (*infile, expfile*)

brainstat.tests.test_stat_threshold.test_01

`brainstat.tests.test_stat_threshold.test_01` ()

brainstat.tests.test_stat_threshold.test_02

`brainstat.tests.test_stat_threshold.test_02` ()

brainstat.tests.test_stat_threshold.test_03

`brainstat.tests.test_stat_threshold.test_03` ()

brainstat.tests.test_stat_threshold.test_04

`brainstat.tests.test_stat_threshold.test_04` ()

brainstat.tests.test_stat_threshold.test_05

`brainstat.tests.test_stat_threshold.test_05` ()

brainstat.tests.test_stat_threshold.test_06

`brainstat.tests.test_stat_threshold.test_06` ()

brainstat.tests.test_stat_threshold.test_07

`brainstat.tests.test_stat_threshold.test_07` ()

brainstat.tests.test_stat_threshold.test_08

`brainstat.tests.test_stat_threshold.test_08` ()

brainstat.tests.test_stat_threshold.test_09

```
brainstat.tests.test_stat_threshold.test_09()
```

brainstat.tests.test_stat_threshold.test_10

```
brainstat.tests.test_stat_threshold.test_10()
```

brainstat.tests.test_stat_threshold.test_11

```
brainstat.tests.test_stat_threshold.test_11()
```

brainstat.tests.test_stat_threshold.test_12

```
brainstat.tests.test_stat_threshold.test_12()
```

brainstat.tests.test_stat_threshold.test_13

```
brainstat.tests.test_stat_threshold.test_13()
```

brainstat.tests.test_stat_threshold.test_14

```
brainstat.tests.test_stat_threshold.test_14()
```

brainstat.tests.test_stat_threshold.test_15

```
brainstat.tests.test_stat_threshold.test_15()
```

brainstat.tests.test_stat_threshold.test_16

```
brainstat.tests.test_stat_threshold.test_16()
```

brainstat.tests.test_stat_threshold.test_17

```
brainstat.tests.test_stat_threshold.test_17()
```

brainstat.tests.test_stat_threshold.test_18

brainstat.tests.test_stat_threshold.test_18()

brainstat.tests.test_stat_threshold.test_19

brainstat.tests.test_stat_threshold.test_19()

brainstat.tests.test_stat_threshold.test_20

brainstat.tests.test_stat_threshold.test_20()

brainstat.tests.test_stat_threshold.test_21

brainstat.tests.test_stat_threshold.test_21()

brainstat.tests.test_stat_threshold.test_22

brainstat.tests.test_stat_threshold.test_22()

brainstat.tests.test_stat_threshold.test_23

brainstat.tests.test_stat_threshold.test_23()

brainstat.tests.test_stat_threshold.test_24

brainstat.tests.test_stat_threshold.test_24()

brainstat.tests.test_stat_threshold.test_25

brainstat.tests.test_stat_threshold.test_25()

brainstat.tests.test_stat_threshold.test_26

brainstat.tests.test_stat_threshold.test_26()

brainstat.tests.test_stat_threshold.test_27

```
brainstat.tests.test_stat_threshold.test_27()
```

brainstat.tests.test_stat_threshold.test_28

```
brainstat.tests.test_stat_threshold.test_28()
```

brainstat.tests.test_stat_threshold.test_29

```
brainstat.tests.test_stat_threshold.test_29()
```

brainstat.tests.test_stat_threshold.test_30

```
brainstat.tests.test_stat_threshold.test_30()
```

brainstat.tests.test_stat_threshold.test_31

```
brainstat.tests.test_stat_threshold.test_31()
```

brainstat.tests.test_stat_threshold.test_32

```
brainstat.tests.test_stat_threshold.test_32()
```

brainstat.tests.test_stat_threshold.test_33

```
brainstat.tests.test_stat_threshold.test_33()
```

brainstat.tests.test_stat_threshold.test_34

```
brainstat.tests.test_stat_threshold.test_34()
```

brainstat.tests.test_stat_threshold.test_35

```
brainstat.tests.test_stat_threshold.test_35()
```

brainstat.tests.test_stat_threshold.test_36

brainstat.tests.test_stat_threshold.test_36()

brainstat.tests.test_stat_threshold.test_37

brainstat.tests.test_stat_threshold.test_37()

brainstat.tests.test_stat_threshold.test_38

brainstat.tests.test_stat_threshold.test_38()

brainstat.tests.test_stat_threshold.test_39

brainstat.tests.test_stat_threshold.test_39()

brainstat.tests.test_stat_threshold.test_40

brainstat.tests.test_stat_threshold.test_40()

brainstat.tests.test_stat_threshold.test_41

brainstat.tests.test_stat_threshold.test_41()

brainstat.tests.test_stat_threshold.test_42

brainstat.tests.test_stat_threshold.test_42()

brainstat.tests.test_stat_threshold.test_43

brainstat.tests.test_stat_threshold.test_43()

brainstat.tests.test_stat_threshold.test_44

brainstat.tests.test_stat_threshold.test_44()

brainstat.tests.test_stat_threshold.test_45

```
brainstat.tests.test_stat_threshold.test_45()
```

brainstat.tests.test_stat_threshold.test_46

```
brainstat.tests.test_stat_threshold.test_46()
```

brainstat.tests.test_stat_threshold.test_47

```
brainstat.tests.test_stat_threshold.test_47()
```

brainstat.tests.test_stat_threshold.test_48

```
brainstat.tests.test_stat_threshold.test_48()
```

brainstat.tests.test_terms

Tests the fixed and mixed effects classes.

Functions

<i>as_variance</i> (M)	
<hr/>	
<i>test_fixed_init</i> ()	Tests the initialization of the FixedEffect class.
<i>test_fixed_overload</i> ()	Tests the overloads of the FixedEffect class.
<i>test_identity_detection</i> ()	Tests that the identity matrix is correctly placed last.
<i>test_mixed_init</i> ()	Tests the initialization of the MixedEffect class.
<i>test_mixed_overload</i> ()	Tests the overloads of the MixedEffect class.

brainstat.tests.test_terms.as_variance

```
brainstat.tests.test_terms.as_variance(M)
```

brainstat.tests.test_terms.test_fixed_init

`brainstat.tests.test_terms.test_fixed_init()`
Tests the initialization of the FixedEffect class.

brainstat.tests.test_terms.test_fixed_overload

`brainstat.tests.test_terms.test_fixed_overload()`
Tests the overloads of the FixedEffect class.

brainstat.tests.test_terms.test_identity_detection

`brainstat.tests.test_terms.test_identity_detection()`
Tests that the identity matrix is correctly placed last.

brainstat.tests.test_terms.test_mixed_init

`brainstat.tests.test_terms.test_mixed_init()`
Tests the initialization of the MixedEffect class.

brainstat.tests.test_terms.test_mixed_overload

`brainstat.tests.test_terms.test_mixed_overload()`
Tests the overloads of the MixedEffect class.

brainstat.tests.testutil

Utilities for running tests and test data generation.

Functions

<code>array2effect(A[, n_random])</code>	Converts an input array to a set of effects.
<code>copy_slm(slm)</code>	Copies an SLM object.
<code>datadir(filename)</code>	Returns the path to a given file in the test data directory.
<code>generate_random_data_model(n_observations, ...)</code>	Generates random test data.
<code>generate_slm(**kwargs)</code>	Generates a SLM with the given attributes :param All attributes of SLM can be provided as keyword arguments.:
<code>save_input_dict(params, basename, test_num)</code>	Saves the input data.
<code>save_slm(slm, basename, testnum[, input])</code>	Saves an SLM object containing test data.
<code>slm2dict(slm)</code>	Converts an SLM to a dictionary.
<code>slm2files(slm, basename, test_num)</code>	Converts an SLM to its output files.

brainstat.tests.testutil.array2effect

`brainstat.tests.testutil.array2effect` (*A*, *n_random=0*)

Converts an input array to a set of effects.

Parameters

- **A** (*np.array*) – A samples-by-effects array.
- **n_random** (*int*, *optional*) – Number of random effects, by default 0. Random effects are selected from the first columns of A.

Returns *brainstat.stats.terms.FixedEffect*, *brainstat.stats.terms.MixedEffect* – The fixed/mixed effects.

brainstat.tests.testutil.copy_slm

`brainstat.tests.testutil.copy_slm` (*slm*)

Copies an SLM object. :param *slm*: SLM object. :type *slm*: *brainstat.stats.SLM.SLM*

Returns *brainstat.stats.SLM.SLM* – SLM object.

brainstat.tests.testutil.datadir

`brainstat.tests.testutil.datadir` (*filename*)

Returns the path to a given file in the test data directory.

Parameters **filename** (*str*) – Name of a file in the data directory.

Returns *str* – Full path to file in the data directory.

brainstat.tests.testutil.generate_random_data_model

`brainstat.tests.testutil.generate_random_data_model` (*n_observations*, *n_vertices*,
n_variates, *n_predictors*)

Generates random test data.

Parameters

- **n_observations** (*int*) – Number of observations.
- **n_vertices** (*int*) – Number of vertices.
- **n_variates** (*int*) – Number of variates.
- **n_predictors** (*int*) – Number of predictors.
- **n_random** (*int*) – Number of random effects.

Returns

- *numpy.ndarray* – Random data.
- *numpy.ndarray* – Random model.

brainstat.tests.testutil.generate_slm

`brainstat.tests.testutil.generate_slm(**kwargs)`

Generates a SLM with the given attributes :param All attributes of SLM can be provided as keyword arguments.:

Returns *brainstat.stats.SLM.SLM* – SLM object.

brainstat.tests.testutil.save_input_dict

`brainstat.tests.testutil.save_input_dict(params, basename, test_num)`

Saves the input data.

Parameters

- **params** (*dict*) – Parameters provided by the parameter grid.
- **basename** (*str*) – Tag to save the file with.
- **test_num** (*int*) – Number of the test.

brainstat.tests.testutil.save_slm

`brainstat.tests.testutil.save_slm(slm, basename, testnum, input=True)`

Saves an SLM object containing test data. :param slm: SLM object. :type slm: *brainstat.stats.SLM.SLM* :param basename: Name for the tested function. :type basename: *str* :param testnum: Test number. :type testnum: *int* :param input: If True, appends *_IN* to filename. If false appends *_OUT*. :type input: *boolean*, optional

Returns *brainstat.stats.SLM.SLM* – SLM object.

brainstat.tests.testutil.slm2dict

`brainstat.tests.testutil.slm2dict(slm)`

Converts an SLM to a dictionary. :param slm: SLM object. :type slm: *brainstat.stats.SLM.SLM*

Returns *dict* – Dictionary with keys equivalent to the attributes of the slm.

brainstat.tests.testutil.slm2files

`brainstat.tests.testutil.slm2files(slm, basename, test_num)`

Converts an SLM to its output files.

Parameters

- **slm** (*brainstat.stats.SLM*) – SLM object.
- **basename** (*str*) – Base name for the file.
- **test_num** (*int*) – Number of the test.

brainstat.tutorial

Functions required for the BrainStat Tutorials

Modules

brainstat.tutorial.utils

brainstat.tutorial.utils

Functions

<i>fetch_abide_data</i> ([<i>data_dir</i> , <i>sites</i> , ...])	Fetches ABIDE cortical thickness data.
<i>fetch_mics_data</i> ([<i>data_dir</i> , <i>overwrite</i>])	Fetches MICS cortical thickness data.

brainstat.tutorial.utils.fetch_abide_data

`brainstat.tutorial.utils.fetch_abide_data` (*data_dir=None*, *sites=None*,
keep_control=True, *keep_patient=True*, *overwrite=False*, *min_rater_ok=3*)

Fetches ABIDE cortical thickness data.

Parameters

- **data_dir** (*str*, *pathlib.Path*, *optional*) – Path to store the MICS data, by default \$HOME_DIR/brainstat_data/mics_data.
- **sites** (*list*, *tuple*, *optional*) – List of sites to include. If none, uses all sites, by default None.
- **keep_control** (*bool*, *optional*) – If true keeps control subjects, by default True.
- **keep_patient** (*bool*, *optional*) – If true keeps patient subjects, by default True.
- **overwrite** (*bool*, *optional*) – If true overwrites existing data, by default False.
- **min_rater_ok** (*int*, *optional*) – Minimum number of raters who approved the data, by default 3.

Returns

- *np.ndarray* – Subject-by-vertex cortical thickness data on fsaverage5.
- *pd.DataFrame* – Subject demographics.

brainstat.tutorial.utils.fetch_mics_data

`brainstat.tutorial.utils.fetch_mics_data` (*data_dir=None, overwrite=False*)

Fetches MICS cortical thickness data.

Parameters

- **data_dir** (*str, pathlib.Path, optional*) – Path to store the MICS data, by default `$HOME_DIR/brainstat_data/mics_data`.
- **overwrite** (*bool, optional*) – If true overwrites existing data, by default False

Returns

- *np.ndarray* – Subject-by-vertex cortical thickness data on fsaverage5.
- *pd.DataFrame* – Subject demographics.

3.3 MATLAB Index

3.3.1 MATLAB Tutorials

For MATLAB tutorials, we recommend viewing these either through the Examples tab on our [FileExchange](#) page, or by opening the files in MATLAB (`PACKAGE_DIRECTORY/tutorials`). Alternatively, we’ve also included copies of these live scripts in ReadTheDocs:

- `matlab_tutorial1`
- `matlab_tutorial2`

3.3.2 MATLAB API

Below are links to descriptions of the important MATLAB functions used in BrainStat.

Statistics

- `matlab_FixedEffect`
- `matlab_MixedEffect`
- `matlab_SLM`

Context Decoding

- `matlab_compute_histology_gradients`
- `matlab_compute_mpc`
- `matlab_fetch_genetic_expression`
- `matlab_read_histology_profile`
- `matlab_surface_decoder`

Datasets

- matlab_fetch_abide_data
- matlab_fetch_gradients
- matlab_fetch_mask
- matlab_fetch_parcellation
- matlab_fetch_template_surface
- matlab_fetch_yeo_networks_metadata

I/O

- matlab_read_surface_data
- matlab_read_surface
- matlab_read_volume
- matlab_write_surface
- matlab_write_volume

3.4 Funding

Our research is kindly supported by:

- Canadian Institutes of Health Research (CIHR)
- National Science and Engineering Research Council of Canada (NSERC)
- Azrieli Center for Autism Research
- The Montreal Neurological Institute]
- Canada Research Chairs Program
- BrainCanada
- SickKids Foundation
- Helmholtz Foundation

We would also like to thank these funders for training/salary support

- Savoy Foundation for Epilepsy (to RV)
- Richard and Ann Sievers Award (to RV)
- Healthy Brain and Healthy Lives (to OB)
- Fonds de la Recherche du Quebec - Sante (to BB)

3.5 Credits

Some references that are incorporated into BrainStat

3.5.1 SurfStat references

Worsley KJ et al. (2009) A Matlab toolbox for the statistical analysis of univariate and multivariate surface and volumetric data using linear mixed effects models and random field theory. *NeuroImage*, Volume 47, Supplement 1, July 2009, Pages S39-S41. [https://doi.org/10.1016/S1053-8119\(09\)70882-1](https://doi.org/10.1016/S1053-8119(09)70882-1)

Chung MK et al. (2010) General Multivariate Linear Modeling of Surface Shapes Using SurfStat *Neuroimage*. 53(2):491-505. doi: 10.1016/j.neuroimage.2010.06.032

3.5.2 Random field theory references

Adler RJ and Taylor JE (2007). *Random fields and geometry*. Springer. Hagler DJ Saygin AP and Sereno MI (2006). Smoothing and cluster thresholding for cortical surface-based group analysis of fMRI data. *NeuroImage*, 33:1093-1103.

Hayasaka S, Phan KL, Liberzon I, Worsley KJ and Nichols TE (2004). Non-Stationary cluster size inference with random field and permutation methods. *NeuroImage*, 22:676-687.

Taylor JE and Adler RJ (2003), Euler characteristics for Gaussian fields on manifolds. *Annals of Probability*, 31:533-563.

Taylor JE and Worsley KJ (2007). Detecting sparse signal in random fields, with an application to brain mapping. *Journal of the American Statistical Association*, 102:913-928.

Worsley KJ, Andermann M, Koulis T, MacDonald D, and Evans AC (1999). Detecting changes in non-isotropic images. *Human Brain Mapping*, 8:98-101.

3.5.3 Multivariate associative techniques

3.5.4 Contextualization

PYTHON MODULE INDEX

b

- [brainstat](#), 31
- [brainstat.context](#), 31
- [brainstat.context.genetics](#), 31
- [brainstat.context.histology](#), 33
- [brainstat.context.meta_analysis](#), 35
- [brainstat.context.resting](#), 36
- [brainstat.datasets](#), 37
- [brainstat.datasets.base](#), 37
- [brainstat.mesh](#), 39
- [brainstat.mesh.data](#), 40
- [brainstat.mesh.interpolate](#), 40
- [brainstat.mesh.utils](#), 43
- [brainstat.stats](#), 44
- [brainstat.stats.SLM](#), 44
- [brainstat.stats.terms](#), 46
- [brainstat.stats.utils](#), 51
- [brainstat.tests](#), 53
- [brainstat.tests.datagen_f](#), 53
- [brainstat.tests.datagen_linear_model](#), 54
- [brainstat.tests.datagen_mesh_edges](#), 54
- [brainstat.tests.datagen_peak_clus](#), 55
- [brainstat.tests.datagen_stat_threshold](#), 56
- [brainstat.tests.datagen_t_test](#), 57
- [brainstat.tests.test_f_test](#), 57
- [brainstat.tests.test_mesh_edges](#), 60
- [brainstat.tests.test_mesh_smooth](#), 61
- [brainstat.tests.test_stat_threshold](#), 61
- [brainstat.tests.test_terms](#), 69
- [brainstat.tests.testutil](#), 70
- [brainstat.tutorial](#), 73
- [brainstat.tutorial.utils](#), 73

Symbols

`__init__()` (*brainstat.stats.SLM.SLM method*), 45
`__init__()` (*brainstat.stats.terms.FixedEffect method*), 49
`__init__()` (*brainstat.stats.terms.MixedEffect method*), 50

A

`apply_mask()` (*in module brainstat.stats.utils*), 51
`array2effect()` (*in module brainstat.tests.testutil*), 71
`as_variance()` (*in module brainstat.tests.test_terms*), 69

B

`brainstat`
 module, 31
`brainstat.context`
 module, 31
`brainstat.context.genetics`
 module, 31
`brainstat.context.histology`
 module, 33
`brainstat.context.meta_analysis`
 module, 35
`brainstat.context.resting`
 module, 36
`brainstat.datasets`
 module, 37
`brainstat.datasets.base`
 module, 37
`brainstat.mesh`
 module, 39
`brainstat.mesh.data`
 module, 40
`brainstat.mesh.interpolate`
 module, 40
`brainstat.mesh.utils`
 module, 43
`brainstat.stats`
 module, 44
`brainstat.stats.SLM`

 module, 44
`brainstat.stats.terms`
 module, 46
`brainstat.stats.utils`
 module, 51
`brainstat.tests`
 module, 53
`brainstat.tests.datagen_f`
 module, 53
`brainstat.tests.datagen_linear_model`
 module, 54
`brainstat.tests.datagen_mesh_edges`
 module, 54
`brainstat.tests.datagen_peak_clus`
 module, 55
`brainstat.tests.datagen_stat_threshold`
 module, 56
`brainstat.tests.datagen_t_test`
 module, 57
`brainstat.tests.test_f_test`
 module, 57
`brainstat.tests.test_mesh_edges`
 module, 60
`brainstat.tests.test_mesh_smooth`
 module, 61
`brainstat.tests.test_stat_threshold`
 module, 61
`brainstat.tests.test_terms`
 module, 69
`brainstat.tests.testutil`
 module, 70
`brainstat.tutorial`
 module, 73
`brainstat.tutorial.utils`
 module, 73

C

`check_duplicate_names()` (*in module brainstat.stats.terms*), 47
`check_names()` (*in module brainstat.stats.terms*), 47
`colon()` (*in module brainstat.stats.utils*), 51

`combine_parcellations()` (in module *brainstat.mesh.interpolate*), 41
`compute_histology_gradients()` (in module *brainstat.context.histology*), 33
`compute_mpc()` (in module *brainstat.context.histology*), 34
`copy_slm()` (in module *brainstat.tests.testutil*), 71
`cortical_ribbon()` (in module *brainstat.mesh.interpolate*), 41

D

`datadir()` (in module *brainstat.tests.testutil*), 71
`download_histology_profiles()` (in module *brainstat.context.histology*), 34
`dummy_test()` (in module *brainstat.tests.test_f_test*), 58
`dummy_test()` (in module *brainstat.tests.test_mesh_edges*), 60
`dummy_test()` (in module *brainstat.tests.test_mesh_smooth*), 61
`dummy_test()` (in module *brainstat.tests.test_stat_threshold*), 64

F

`f_test()` (in module *brainstat.stats.SLM*), 44
`fetch_abide_data()` (in module *brainstat.tutorial.utils*), 73
`fetch_gradients()` (in module *brainstat.datasets.base*), 37
`fetch_mask()` (in module *brainstat.datasets.base*), 38
`fetch_mics_data()` (in module *brainstat.tutorial.utils*), 74
`fetch_parcellation()` (in module *brainstat.datasets.base*), 38
`fetch_template_surface()` (in module *brainstat.datasets.base*), 39
`fetch_yeo_networks_metadata()` (in module *brainstat.datasets.base*), 39
`fit()` (*brainstat.stats.SLM.SLM method*), 46
`FixedEffect` (class in *brainstat.stats.terms*), 48

G

`generate_data_test_mesh_edges()` (in module *brainstat.tests.datagen_mesh_edges*), 55
`generate_f_test_out()` (in module *brainstat.tests.datagen_f*), 54
`generate_peak_clus_out()` (in module *brainstat.tests.datagen_peak_clus*), 55
`generate_random_data_model()` (in module *brainstat.tests.testutil*), 71
`generate_random_mesh_edge_data()` (in module *brainstat.tests.datagen_mesh_edges*), 55
`generate_random_slm()` (in module *brainstat.tests.datagen_peak_clus*), 56

`generate_random_two_slms()` (in module *brainstat.tests.datagen_f*), 54
`generate_slm()` (in module *brainstat.tests.testutil*), 72
`generate_stat_threshold_out()` (in module *brainstat.tests.datagen_stat_threshold*), 56
`generate_test_data()` (in module *brainstat.tests.datagen_f*), 54
`generate_test_data()` (in module *brainstat.tests.datagen_linear_model*), 54
`generate_test_data()` (in module *brainstat.tests.datagen_peak_clus*), 56
`generate_test_data()` (in module *brainstat.tests.datagen_stat_threshold*), 56
`generate_test_data()` (in module *brainstat.tests.datagen_t_test*), 57
`get_index()` (in module *brainstat.stats.terms*), 47
`get_meshedge_output()` (in module *brainstat.tests.datagen_mesh_edges*), 55
`gradients_corr()` (in module *brainstat.context.resting*), 36

I

`interp1()` (in module *brainstat.stats.utils*), 51
`ismember()` (in module *brainstat.stats.utils*), 52

L

`load_mesh_labels()` (in module *brainstat.mesh.interpolate*), 41

M

`mesh_edges()` (in module *brainstat.mesh.utils*), 44
`mesh_smooth()` (in module *brainstat.mesh.data*), 40
`meta_analytic_decoder()` (in module *brainstat.context.meta_analysis*), 35
`MixedEffect` (class in *brainstat.stats.terms*), 49
module
 brainstat, 31
 brainstat.context, 31
 brainstat.context.genetics, 31
 brainstat.context.histology, 33
 brainstat.context.meta_analysis, 35
 brainstat.context.resting, 36
 brainstat.datasets, 37
 brainstat.datasets.base, 37
 brainstat.mesh, 39
 brainstat.mesh.data, 40
 brainstat.mesh.interpolate, 40
 brainstat.mesh.utils, 43
 brainstat.stats, 44
 brainstat.stats.SLM, 44
 brainstat.stats.terms, 46
 brainstat.stats.utils, 51
 brainstat.tests, 53

brainstat.tests.datagen_f, 53
 brainstat.tests.datagen_linear_model, 54
 brainstat.tests.datagen_mesh_edges, 54
 brainstat.tests.datagen_peak_clus, 55
 brainstat.tests.datagen_stat_threshold, 56
 brainstat.tests.datagen_t_test, 57
 brainstat.tests.test_f_test, 57
 brainstat.tests.test_mesh_edges, 60
 brainstat.tests.test_mesh_smooth, 61
 brainstat.tests.test_stat_threshold, 61
 brainstat.tests.test_terms, 69
 brainstat.tests.testutil, 70
 brainstat.tutorial, 73
 brainstat.tutorial.utils, 73
 multi_surface_to_volume() (in module brainstat.mesh.interpolate), 42
 multiple_comparison_corrections() (brainstat.stats.SLM.SLM method), 46

P

params2files() (in module brainstat.tests.datagen_f), 54
 params2files() (in module brainstat.tests.datagen_peak_clus), 56
 params2files() (in module brainstat.tests.datagen_stat_threshold), 57
 partial_correlation() (in module brainstat.context.histology), 35

R

read_histology_profile() (in module brainstat.context.histology), 35
 read_surface_gz() (in module brainstat.mesh.interpolate), 42
 remove_duplicate_columns() (in module brainstat.stats.terms), 47
 remove_identical_columns() (in module brainstat.stats.terms), 47
 ribbon_interpolation() (in module brainstat.mesh.interpolate), 42
 row_ismember() (in module brainstat.stats.utils), 52

S

save_input_dict() (in module brainstat.tests.testutil), 72
 save_slm() (in module brainstat.tests.testutil), 72
 set_identity_last() (brainstat.stats.terms.MixedEffect method), 50
 SLM (class in brainstat.stats.SLM), 45
 slm2dict() (in module brainstat.tests.testutil), 72
 slm2files() (in module brainstat.tests.testutil), 72
 surface_genetic_expression() (in module brainstat.context.genetics), 32
 surface_to_volume() (in module brainstat.mesh.interpolate), 43

T

test_01() (in module brainstat.tests.test_f_test), 58
 test_01() (in module brainstat.tests.test_mesh_edges), 60
 test_01() (in module brainstat.tests.test_mesh_smooth), 61
 test_01() (in module brainstat.tests.test_stat_threshold), 64
 test_02() (in module brainstat.tests.test_f_test), 58
 test_02() (in module brainstat.tests.test_mesh_edges), 61
 test_02() (in module brainstat.tests.test_stat_threshold), 64
 test_03() (in module brainstat.tests.test_f_test), 58
 test_03() (in module brainstat.tests.test_mesh_edges), 61
 test_03() (in module brainstat.tests.test_stat_threshold), 64
 test_04() (in module brainstat.tests.test_f_test), 58
 test_04() (in module brainstat.tests.test_mesh_edges), 61
 test_04() (in module brainstat.tests.test_stat_threshold), 64
 test_05() (in module brainstat.tests.test_f_test), 58
 test_05() (in module brainstat.tests.test_stat_threshold), 64
 test_06() (in module brainstat.tests.test_f_test), 59
 test_06() (in module brainstat.tests.test_stat_threshold), 64
 test_07() (in module brainstat.tests.test_f_test), 59
 test_07() (in module brainstat.tests.test_stat_threshold), 64
 test_08() (in module brainstat.tests.test_f_test), 59
 test_08() (in module brainstat.tests.test_stat_threshold), 64
 test_09() (in module brainstat.tests.test_f_test), 59
 test_09() (in module brainstat.tests.test_stat_threshold), 65
 test_10() (in module brainstat.tests.test_f_test), 59
 test_10() (in module brainstat.tests.test_stat_threshold), 65
 test_11() (in module brainstat.tests.test_f_test), 59
 test_11() (in module brainstat.tests.test_stat_threshold), 65
 test_12() (in module brainstat.tests.test_f_test), 59
 test_12() (in module brainstat.tests.test_stat_threshold), 65

test_13 () (in module *brainstat.tests.test_f_test*), 59
 test_13 () (in module *brainstat.tests.test_stat_threshold*), 65
 test_14 () (in module *brainstat.tests.test_f_test*), 59
 test_14 () (in module *brainstat.tests.test_stat_threshold*), 65
 test_15 () (in module *brainstat.tests.test_f_test*), 60
 test_15 () (in module *brainstat.tests.test_stat_threshold*), 65
 test_16 () (in module *brainstat.tests.test_f_test*), 60
 test_16 () (in module *brainstat.tests.test_stat_threshold*), 65
 test_17 () (in module *brainstat.tests.test_stat_threshold*), 65
 test_18 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_19 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_20 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_21 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_22 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_23 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_24 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_25 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_26 () (in module *brainstat.tests.test_stat_threshold*), 66
 test_27 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_28 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_29 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_30 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_31 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_32 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_33 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_34 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_35 () (in module *brainstat.tests.test_stat_threshold*), 67
 test_36 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_37 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_38 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_39 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_40 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_41 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_42 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_43 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_44 () (in module *brainstat.tests.test_stat_threshold*), 68
 test_45 () (in module *brainstat.tests.test_stat_threshold*), 69
 test_46 () (in module *brainstat.tests.test_stat_threshold*), 69
 test_47 () (in module *brainstat.tests.test_stat_threshold*), 69
 test_48 () (in module *brainstat.tests.test_stat_threshold*), 69
 test_fixed_init () (in module *brainstat.tests.test_terms*), 70
 test_fixed_overload () (in module *brainstat.tests.test_terms*), 70
 test_identity_detection () (in module *brainstat.tests.test_terms*), 70
 test_mixed_init () (in module *brainstat.tests.test_terms*), 70
 test_mixed_overload () (in module *brainstat.tests.test_terms*), 70
 to_df () (in module *brainstat.stats.terms*), 48
 brain-undo_mask () (in module *brainstat.stats.utils*), 52
 Y
 yeo_networks_associations () (in module *brainstat.context.resting*), 36