Package 'fbst'

July 22, 2025

Type Package

Title The Full Bayesian Evidence Test, Full Bayesian Significance Test and the e-Value

Version 2.2

Date 2024-02-14

Author Riko Kelter

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Description Provides access to a range of functions for computing and visualizing the Full Bayesian Significance Test (FBST) and the e-value for testing a sharp hypothesis against its alternative, and the Full Bayesian Evidence Test (FBET) and the (generalized) Bayesian evidence value for testing a composite (or interval) hypothesis against its alternative. The methods are widely applicable as long as a posterior MCMC sample is available.

Imports bayestestR, methods

Depends cubature, ks, viridis, rstanarm

Suggests BayesFactor, knitr, rmarkdown

License GPL-3

VignetteBuilder knitr

NeedsCompilation no

Repository CRAN

Date/Publication 2024-02-15 08:00:02 UTC

Contents

`fbst-package` *The Full Bayesian Evidence Test, Full Bayesian Significance Test and the e-Value*

Description

Provides access to a range of functions for computing and visualizing the Full Bayesian Significance Test (FBST) and the e-value for testing a sharp hypothesis against its alternative, and the Full Bayesian Evidence Test (FBET) and the (generalized) Bayesian evidence value for testing a composite (or interval) hypothesis against its alternative. The methods are widely applicable as long as a posterior MCMC sample is available.

Details

Package for conducting the Full Bayesian Evidence Test (FBET) and the Full Bayesian Significance Test (FBST). The FBST is a Bayesian hypothesis test for testing a sharp hypothesis against its alternative by calculating the e-value, the Bayesian evidence against the null hypothesis. The FBET is a generalization of the underlying Pereira-Stern theory of the FBST and allows for testing interval hypotheses. It provides the Bayesian evidence value, or generalized e-value, which includes the e-value of the FBST as a special case. The Bayesian evidence value is based on the relative surprise function to a reference function. In the FBST, the tangential set corresponding to a sharp null hypothesis serves for quantifying the Bayesian evidence. In the FBET, the Bayesian evidence interval serves for quantifying the Bayesian evidence, which has a strong analogy to the Bayes factor. Next to the core functions, helper functions and visualizations of the results of a FBST and FBET are provided in the package.

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Title:	The Full Bayesian Evidence Test, Full Bayesian Significance Test and the e-Value
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Imports:	bayestestR, methods
Depends:	cubature, ks, viridis, rstanarm
Suggests:	BayesFactor, knitr, rmarkdown

License: GPL-3
VignetteBuilder: knitr

Index of help topics:

Author(s)

Riko Kelter

Maintainer: Riko Kelter <riko_k@gmx.de>

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

`access-method` *Returns an object from an object of class* `fbst`.

Description

Returns an object from an object of class `fbst`

Details

-

Value

-

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 3, dimensionNullset = 2)

# Return the e-value from an fbst object
res$eValue
```

---

access_fbet-method *Returns an object from an object of class* fbet.

Description

Returns an object from an object of class fbet

Details

-

Value

-

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)

# Return the Bayesian evidence value for the interval null hypothesis
res$eValueH0
```

---

bdm *bdm*

Description

Calculates the Bayesian discrepancy measure for a precise null hypothesis.

Usage

```
bdm(posteriorDensityDraws, nullHypothesisValue=0)
```

Arguments

`posteriorDensityDraws`
: Vector of (MCMC) posterior parameter draws.

`nullHypothesisValue`
: Parameter value of the precise null hypothesis. Defaults to zero.

Details

The BDM is calculated as $\delta_H(x) := 2 \cdot P(\theta \in I_H(x)|x)$ where $I_H(x) := (m, \theta_0)$ if $m < \theta_0$, $I_H(x) := \{m\}$ if $m = \theta_0$ and $I_H(x) := (\theta_0, m)$ if $m > \theta_0$, where m denotes the posterior median of the parameter θ, and the null hypothesis specifies $H_0 : \theta = \theta_0$.

Value

Returns the value $\delta_H(x)$ of the BDM.

Author(s)

Riko Kelter

References

For details, see: https://arxiv.org/abs/2105.13716

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

bdm(p,0)
```

`fbet` *fbet*

Description

The function computes the Full Bayesian Evidence Test (FBST) and the Bayesian evidence value (the generalized e-value which obtains the e-value of the FBST as a special case), which is the Bayesian evidence against an interval null hypothesis. The function assumes posterior MCMC draws and constructs a posterior density based on a kernel density estimator subsequently. The Bayesian evidence interval is computed using a linear search based on the evidence-threshold and the calculation of the Bayesian evidence value is performed using numerical integration.

Usage

```
fbet(posteriorDensityDraws=NULL, interval, nu=1, FUN=NULL,
par=NULL, posterior=NULL, par_posterior=NULL)
```

Arguments

`posteriorDensityDraws`	Vector of MCMC posterior parameter draws
`interval`	Vector of two numerical values containing the boundaries of the interval null hypothesis to be tested
`nu`	Numerical value which provides the evidence-threshold based on which the Bayesian evidence interval is calculated
`FUN`	Reference function
`par`	Additional parameters of the reference function
`posterior`	Posterior density function
`par_posterior`	Additional parameters of the posterior density function

Details

If no reference function is specified, a flat reference function $r(\theta) = 1$ is used as default reference function when posteriorDensityDraws are provided.

Value

Returns an object of class fbet if posteriorDensityDraws are provided. When using the posterior argument to pass the posterior as a function, it provides the evidence value for the hypothesis specified in the interval argument.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.3,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function, nu = 0
res = fbet(p, interval = c(-0.1,0.1), nu=0, FUN=NULL, par=NULL)
summary(res)
plot(res)

# flat reference function, nu = 1
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)
summary(res)
plot(res)

# medium Cauchy C(0,1) reference function, nu = 1
res_med = fbet(posteriorDensityDraws = p, interval = c(-0.1,0.1), nu = 1,
FUN = dcauchy, par = list(location = 0, scale=sqrt(2)))
summary(res_med)
plot(res_med)

# posterior as function argument
fbet(posterior=dbeta, par_posterior = list(shape1 = 3, shape2 = 4),
interval = c(0.2,1), nu = 1, FUN=dbeta, par = list(shape1 = 1, shape2 = 1))
```

fbet-class *Class* "fbet-class"

Description

Class for modelling the results of a Full Bayesian Evidence Test

Objects from the Class

Store the results of a FBET

Slots

`data`: Object of class `"list"` holding the results of the Full Bayesian Evidence Test. `posteriorDensityDraws` holds the posterior MCMC parameter draws, `posteriorDensityDrawsSorted` stores the sorted posterior MCMC parameter draws, `postDensValues` stores the posterior density values, `indices` stores the indices for deciding which values pass the evidence-threshold ν, `interval` stores the boundaries of the interval null hypothesis, `referenceFunction` stores the name of the reference function used, `nu` specifies the evidence-threshold used for computation of the Bayesian evidence interval, `evidenceInterval` holds the endpoints of the resulting Bayesian evidence interval, `eValueH0` holds the Bayesian evidence value in favour of the interval null hypothesis, `eValueH1` holds the Bayesian evidence value in favour of the alternative hypothesis (or equivalently, against the interval null hypothesis)

fbst *fbst*

Description

The function computes the Full Bayesian Significance Test (FBST) and the e-value, which is the Bayesian evidence against a precise null hypothesis. The function assumes posterior MCMC draws and constructs a posterior density based on a kernel density estimator subsequently.

Usage

```
fbst(posteriorDensityDraws, nullHypothesisValue, FUN, par,
dimensionTheta, dimensionNullset, dim, gridSize)
```

Arguments

`posteriorDensityDraws`	Vector of (MCMC) posterior parameter draws.
`nullHypothesisValue`	Parameter value of the precise null hypothesis.
`FUN`	Reference function.

par	Additional parameters of the reference function.
dimensionTheta	Dimension of the parameter space, defaults to 1 and can be changed to 2. Dimensions larger than 2 are currently not supported.
dimensionNullset	Dimension of the null set corresponding to the null hypothesis.
dim	Dimension of the posterior subspace over which integration is required. Defaults to 1. Can be changed to 2 if required.
gridSize	Grid size for the multivariate two-dimensional kernel density estimation in case dimensionTheta=2. Defaults to 1000.

Details

If no reference function is specified, a flat reference function $r(\theta) = 1$ is used as default reference function. Note that the posterior dimension dim defaults to 1, and if dim=2, only flat reference functions are supported. Thus, specifying FUN or par has no effect when dim=2.

Value

Returns an object of class fbst.

Author(s)

Riko Kelter

References

For a details, see: https://link.springer.com/article/10.3758/s13428-021-01613-6.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 2, dimensionNullset = 1)
summary(res)
plot(res)

# medium Cauchy C(0,1) reference function
res_med = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0, dimensionTheta = 2,
dimensionNullset = 1, FUN = dcauchy, par = list(location = 0, scale = sqrt(2)/2))
summary(res_med)
plot(res_med)
```

fbst-class *Class* "fbst-class"

Description

Class for modelling the results of a Full Bayesian Significance Test

Objects from the Class

Store the results of a FBST

Slots

data: Object of class "list" holding the results of the Full Bayesian Significance Test. posteriorDensityDraws holds the posterior MCMC parameter draws, postEffSizeSorted stores the sorted posterior MCMC parameter draws, densZero stores the surprise function value at the sharp null hypothesis parameter value, postDensValues stores the posterior density values, indices stores the indices for deciding which values are located inside the tangential set, nullHypothesisValue stores the sharp null hypothesis parameter value, referenceFunction holds the name of the reference function used, dimensionTheta holds the dimension of the parameter space, dimensionNullset holds the dimension of the null set corresponding to the null hypothesis, eValue holds the Bayesian evidence against the sharp null hypothesis, the e-value, pValue holds the p-value associated with the Bayesian e-value in favour of the sharp null hypothesis, sev_H_0 holds the standardized e-value as a replacement of the frequentist p-value.

names.fbet *names.fbet*

Description

Plots the names of the objects stored in the data object of a Full Bayesian Evidence Test.

Usage

```
## S3 method for class 'fbet'
names(x)
```

Arguments

x	An Object of class "fbet".

Details

Plots the names of the objects stored in the data object of a Full Bayesian Evidence Test.

Value

Returns a list of names.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)
names(res)
```

`names.fbst` *names.fbst*

Description

Plots the names of the objects stored in the `data` object of a Full Bayesian Significance Test.

Usage

```
## S3 method for class 'fbst'
names(x)
```

Arguments

`x`	An Object of class `"fbst"`.

Details

Plots the names of the objects stored in the `data` object of a Full Bayesian Significance Test.

Value

Returns a list of names.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 2, dimensionNullset = 1)
names(res)
```

---

plot.fbet *plot.fbet*

Description

Plots the results of a Full Bayesian Evidence Test.

Usage

```
## S3 method for class 'fbet'
plot(x, ..., leftBoundary = -100, rightBoundary = 100, type = "posterior",
legendposition = "topleft", main = "")
```

Arguments

x	An Object of class "fbet".
...	Additional parameters, see "plot(x, ...)".
leftBoundary	x-coordinate for the left boundary to which is used for visualising the results. Defaults to -100.
rightBoundary	x-coordinate for the right boundary to which is used for visualising the results. Defaults to 100.
type	Defaults to "posterior", which produces a posterior-density based plot. Can be changed to "surprise" to show the surprise function instead.
legendposition	Position of the legend. Defaults to "topleft". Must be one of the standard string values available for the legend function of base R.
main	Title string for the plot. Default to no title.

Details

Plots the resulting surprise function, the interval null hypothesis (dotted blue lines), the resulting Bayesian evidence interval (solid blue lines), the evidence-threshold ν (dotted black line) and the resulting Bayesian evidence values. The Bayesian evidence value in favour of the interval null hypothesis is visualized as the blue area, and the Bayesian evidence value in favour of the alternative hypothesis is visualized as the red area.

Value

Returns a plot.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.3,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)
summary(res)
plot(res)
```

`plot.fbst` *plot.fbst*

Description

Plots the results of a Full Bayesian Significance Test.

Usage

```
## S3 method for class 'fbst'
plot(x, ..., leftBoundary = -100, rightBoundary = 100, type = "contour", parNames = NULL,
xlimleft = NULL, xlimright = NULL, xlabString = "Parameter", ylabString = NULL)
```

Arguments

x	An Object of class "fbst".
...	Additional parameters, see "plot(x, ...)".
leftBoundary	x-coordinate for the left boundary to which is used for visualising the evidence in support of the null hypothesis. Defaults to -100.
rightBoundary	x-coordinate for the right boundary to which is used for visualising the evidence in support of the null hypothesis. Defaults to 100.
type	Relevant only if dim=2. Defaults to "contour" which provides a contour plot of the posterior, with a magenta point that shows the supremum over the null set. Alternatively, "persp" provides a 3-dimensional perspective plot of the posterior.
parNames	Vector of two entries which specifies the names for the parameters. Only relevant if dimensionTheta=2.
xlimleft	The left value for the x-axis range for the plot. Defaults to the minimum value provided in the posterior draws stored in the FBST object.
xlimright	The right value for the x-axis range for the plot. Defaults to the maximum value provided in the posterior draws stored in the FBST object.
xlabString	String for the x-axis label. Defaults to "Parameter".
ylabString	String for the y-axis label. Default to "density".

Details

Plots the surprise function, the supremum of the surprise function restricted to the null set (blue point) and visualises the Bayesian e-value against the sharp null hypothesis as the blue shaded area under the surprise function. The Bayesian e-value in favour of the sharp null hypothesis is visualised as the red shaded area under the surprise function.

Value

Returns a plot.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])
```

```
# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 2, dimensionNullset = 1)
plot(res)
plot(res, xlimleft = -1.5, xlimright = 0.5)
```

---

show.fbet *show.fbet*

Description

Prints the main results of a Full Bayesian Evidence Test to the console.

Usage

```
## S3 method for class 'fbet'
show(object)
```

Arguments

object	An Object of class "fbet".

Details

Shows the main results of a Full Bayesian Evidence Test stored in an object of class fbet.

Value

Prints the results onto the console.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])
```

```
# flat reference function
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)
show(res)
```

---

show.fbst *show.fbst*

Description

Prints the main results of a Full Bayesian Significance Test to the console.

Usage

```
## S3 method for class 'fbst'
show(object)
```

Arguments

object	An Object of class "fbst".

Details

Shows the main results of a Full Bayesian Significance Test stored in an object of class fbst.

Value

Prints the results onto the console.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 2, dimensionNullset = 1)
show(res)
```

summary.fbet *summary.fbet*

Description

Prints the results of a Full Bayesian Evidence Test.

Usage

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

Arguments

object	An Object of class "fbet".
...	Additional parameters, see "summary(object, ...)".

Details

Summarises the results of a Full Bayesian Evidence Test.

Value

Prints the results onto the console.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.3,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbet(p, interval = c(-0.1,0.1), nu=1, FUN=NULL, par=NULL)
summary(res)
```

summary.fbst *summary.fbst*

Description

Prints the results of a Full Bayesian Significance Test.

Usage

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

Arguments

object	An Object of class "fbst".
...	Additional parameters, see "summary(object, ...)".

Details

Summarises the results of a Full Bayesian Significance Test.

Value

Prints the results onto the console.

Author(s)

Riko Kelter

References

For a details, see: https://arxiv.org/abs/2001.10577 and https://arxiv.org/pdf/2001.10577.pdf.

Examples

```
set.seed(57)
grp1=rnorm(50,0,1.5)
grp2=rnorm(50,0.8,3.2)

p = as.vector(BayesFactor::ttestBF(x=grp1,y=grp2,
  posterior = TRUE, iterations = 3000,
  rscale = "medium")[,4])

# flat reference function
res = fbst(posteriorDensityDraws = p, nullHypothesisValue = 0,
dimensionTheta = 2, dimensionNullset = 1)
summary(res)
```

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