

Package ‘ebnm’

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BugReports <https://github.com/stephenslab/ebnm/issues>

Description Provides simple, fast, and stable functions to fit the normal means model using empirical Bayes. For available models and details, see function `ebnm()`. A detailed introduction to the package is provided by Willwerscheid and Stephens (2021) <[doi:10.48550/arXiv.2110.00152](https://doi.org/10.48550/arXiv.2110.00152)>.

License GPL (>= 3)

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coef.ebnm

*Extract posterior means from a fitted EBNM model***Description**

The `coef` method for class `ebnm`.

Usage

```
## S3 method for class 'ebnm'
coef(object, ...)
```

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>...</code>	Not used. Included for consistency as an S3 method.

confint.ebnm

*Obtain confidence intervals using a fitted EBNM model***Description**

The `confint` method for class `ebnm`. Estimates the highest posterior density (HPD) intervals by sampling from the posterior. By default, `ebnm` does not return a posterior sampler; one can be added to the `ebnm` object using function `ebnm_add_sampler`.

Usage

```
## S3 method for class 'ebnm'
confint(object, parm, level = 0.95, nsim = 1000, ...)
```

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>parm</code>	A vector of numeric indices specifying which means θ_i are to be given confidence intervals. If missing, all observations are considered.
<code>level</code>	The confidence level required.
<code>nsim</code>	The number of samples to use to estimate confidence intervals.
<code>...</code>	Additional arguments to be passed to the posterior sampler function. Since <code>ebnm_horseshoe</code> returns an MCMC sampler, it takes parameter <code>burn</code> , the number of burn-in samples to discard. At present, no other samplers take any additional parameters.

Value

A matrix with columns giving lower and upper confidence limits for each mean θ_i . These will be labelled as "CI.lower" and "CI.upper".

 ebnm

 Solve the EBNM problem

Description

Solves the empirical Bayes normal means (EBNM) problem using a specified family of priors. For an article-length introduction to the package, see Willwerscheid and Stephens (2021), cited in **References** below.

Usage

```
ebnm(
  x,
  s = 1,
  prior_family = c("point_normal", "point_laplace", "point_exponential", "normal",
    "horseshoe", "normal_scale_mixture", "unimodal", "unimodal_symmetric",
    "unimodal_nonnegative", "unimodal_nonpositive", "generalized_binary", "npmle",
    "deconvolver", "flat", "point_mass", "ash"),
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL,
  ...
)

ebnm_output_default()

ebnm_output_all()
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed. Two prior families have additional restrictions: when horseshoe priors are used, errors must be homoskedastic; and since function deconv in package <code>deconvolveR</code> takes z -scores, the "deconvolver" family requires that all standard errors be equal to 1.
<code>prior_family</code>	A character string that specifies the prior family G . See Details below.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data. This parameter is ignored by the NPMLE, the <code>deconvolveR</code> family, and the improper uniform (or "flat") prior. For generalized binary priors, which are bimodal, the mode parameter specifies the mode of the truncated normal component (the location of the point mass is fixed at zero).

scale	A scalar or vector specifying the scale parameter(s) of the prior or "estimate" if the scale parameters are to be estimated from the data. This parameter is ignored by the flat prior and the family of point mass priors. The interpretation of scale depends on the prior family. For normal and point-normal families, it is a scalar specifying the standard deviation of the normal component. For point-Laplace and point-exponential families, it is a scalar specifying the scale parameter of the Laplace or exponential component. For the horseshoe family, it corresponds to $s\tau$ in the usual parametrization of the horseshoe distribution. For the family of generalized binary priors, it specifies the ratio of the (untruncated) standard deviation of the normal component to its mode. This ratio must be fixed in advance (i.e., argument "estimate" is unavailable for generalized binary priors). For the NPMLE and deconvolveR prior family, scale is a scalar specifying the distance between successive means in the grid of point masses or normal distributions used to estimate g. For all other prior families, which are implemented using the function ash in package ashr, it is a vector specifying the parameter <code>mixsd</code> to be passed to <code>ash</code> or "estimate" if <code>mixsd</code> is to be chosen by <code>ebnm</code>. (Note that <code>ebnm</code> chooses <code>mixsd</code> differently from <code>ash</code>: see functions ebnm_scale_normalmix, ebnm_scale_unimix, and ebnm_scale_npmle for details. To use the <code>ash</code> grid, set <code>scale = "estimate"</code> and pass in <code>gridmult</code> as an additional parameter. See ash for defaults and details.)
g_init	The prior distribution g. Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code>, <code>g_init</code> specifies the initial value of g used during optimization. For non-parametric priors, this has the side effect of fixing the mode and scale parameters. If <code>g_init</code> is supplied, it should be an object of class normalmix for normal, point-normal, scale mixture of normals, and deconvolveR prior families, as well as for the NPMLE; class laplacemix for point-Laplace families; class gammamix for point-exponential families; class horseshoe for horseshoe families; class unimix for unimodal_ families; or class tnormalmix for generalized binary priors. An object of class <code>ebnm</code> can also be supplied as argument, provided that field <code>fitted_g</code> contains a prior of the correct class (see Examples below).
fix_g	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
output	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
optmethod	A string specifying which optimization function is to be used. Since all non-parametric families rely upon external packages, this parameter is only available for parametric families (point-normal, point-Laplace, point-exponential, and normal). Options include "nlm", "lbfgsb" (which calls <code>optim</code> with method = "L-BFGS-B"), and "trust" (which calls into package <code>trust</code>). Other options are "nohess_nlm", "nograd_nlm", and "nograd_lbfgsb", which use numerical approximations rather than exact expressions for the Hessian and (for the latter two) the gradient. The default option is "nohess_nlm".
control	A list of control parameters to be passed to the optimization function. optimize

is used for normal and horseshoe prior families, while `nlm` is used for parametric families unless parameter `optmethod` specifies otherwise. `nlm` is also used for the `deconvolveR` prior family. For ash families (including scale mixtures of normals, the NPMLE, and all `unimodal_` families), function `mixsqp` in package `mixsqp` is the default. For generalized binary priors, function `optim` is used with `method = "L-BFGS-B"`.

...

Additional parameters. When a `unimodal_` prior family is used, these parameters are passed to function `ash` in package `ashr`. Although it does not call into `ashr`, the scale mixture of normals family accepts parameter `gridmult` for purposes of comparison. When `gridmult` is set, an `ashr`-style grid will be used instead of the default `ebnm` grid. When the "deconvolver" family is used, additional parameters are passed to function `deconv` in package `deconvolveR`. Families of generalized binary priors take several additional parameters; see `ebnm_generalized_binary`. In all other cases, additional parameters are ignored.

Details

Given vectors of data x and standard errors s , `ebnm` solves the "empirical Bayes normal means" (EBNM) problem for various choices of prior family. The model is

$$x_j | \theta_j, s_j \sim N(\theta_j, s_j^2)$$

$$\theta_j \sim g \in G,$$

where g , which is referred to as the "prior distribution" for θ , is to be estimated from among some specified family of prior distributions G . Several options for G are implemented, some parametric and others non-parametric; see below for examples.

Solving the EBNM problem involves two steps. First, $g \in G$ is estimated via maximum marginal likelihood:

$$\hat{g} := \arg \max_{g \in G} L(g),$$

where

$$L(g) := \prod_j \int p(x_j | \theta_j, s_j) g(d\theta_j).$$

Second, posterior distributions $p(\theta_j | x_j, s_j, \hat{g})$ and/or summaries such as posterior means and posterior second moments are computed.

Implemented prior families include:

`point_normal` The family of mixtures where one component is a point mass at μ and the other is a normal distribution centered at μ .

`point_laplace` The family of mixtures where one component is a point mass at μ and the other is a double-exponential distribution centered at μ .

`point_exponential` The family of mixtures where one component is a point mass at μ and the other is a (nonnegative) exponential distribution with mode μ .

`normal` The family of normal distributions.

`horseshoe` The family of `horseshoe` distributions.

`normal_scale_mixture` The family of scale mixtures of normals.

`unimodal` The family of all unimodal distributions.

`unimodal_symmetric` The family of symmetric unimodal distributions.

`unimodal_nonnegative` The family of unimodal distributions with support constrained to be greater than the mode.

`unimodal_nonpositive` The family of unimodal distributions with support constrained to be less than the mode.

`generalized_binary` The family of mixtures where one component is a point mass at zero and the other is a truncated normal distribution with lower bound zero and nonzero mode. See Liu et al. (2023), cited in **References** below.

`npmle` The family of all distributions.

`deconvolver` A non-parametric exponential family with a natural spline basis. Like `npmle`, there is no unimodal assumption, but whereas `npmle` produces spiky estimates for g , `deconvolver` estimates are much more regular. See [deconvolveR-package](#) for details and references.

`flat` The "non-informative" improper uniform prior, which yields posteriors

$$\theta_j | x_j, s_j \sim N(x_j, s_j^2).$$

`point_mass` The family of point masses δ_μ . Posteriors are point masses at μ .

`ash` Calls into function [ash](#) in package `ashr`. Can be used to make direct comparisons of `ebnm` and `ashr` implementations of prior families such as scale mixtures of normals and the NPMLE.

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$ (an object of class [normalmix](#), [laplacemix](#), [gammamix](#), [unimix](#), [tnormalmix](#), or [horseshoe](#)).

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. For all prior families other than the horseshoe, the sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation. Since `ebnm_horseshoe` returns an MCMC sampler, it additionally takes parameter `burn`, the number of burn-in samples to discard.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

Functions

- `ebnm_output_default()`: Lists the default return values.
- `ebnm_output_all()`: Lists all valid return values.

References

Jason Willwerscheid and Matthew Stephens (2021). ebnm: an R Package for solving the empirical Bayes normal means problem using a variety of prior families. arXiv:2110.00152.

Yusha Liu, Peter Carbonetto, Jason Willwerscheid, Scott A Oakes, Kay F Macleod, and Matthew Stephens (2023). Dissecting tumor transcriptional heterogeneity from single-cell RNA-seq data by generalized binary covariance decomposition. bioRxiv 2023.08.15.553436.

See Also

A plotting method is available for ebnm objects: see [plot.ebnm](#).

For other methods, see [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

Calling into functions [ebnm_point_normal](#), [ebnm_point_laplace](#), [ebnm_point_exponential](#), [ebnm_normal](#), [ebnm_horseshoe](#), [ebnm_normal_scale_mixture](#), [ebnm_unimodal](#), [ebnm_unimodal_symmetric](#), [ebnm_unimodal_nonnegative](#), [ebnm_unimodal_nonpositive](#), [ebnm_generalized_binary](#), [ebnm_npmle](#), [ebnm_deconvolver](#), [ebnm_flat](#), [ebnm_point_mass](#), and [ebnm_ash](#) is equivalent to calling into [ebnm](#) with `prior_family` set accordingly.

Examples

```
theta <- c(rep(0, 100), rexp(100))
s <- 1
x <- theta + rnorm(200, 0, s)

# The following are equivalent:
pn.res <- ebnm(x, s, prior_family = "point_normal")
pn.res <- ebnm_point_normal(x, s)

# Inspect results:
logLik(pn.res)
plot(pn.res)

# Fix the scale parameter:
pl.res <- ebnm_point_laplace(x, s, scale = 1)

# Estimate the mode:
normal.res <- ebnm_normal(x, s, mode = "estimate")
plot(normal.res) # posterior means shrink to a value different from zero

# Use an initial g (this fixes mode and scale for ash priors):
normalmix.res <- ebnm_normal_scale_mixture(x, s, g_init = pn.res)

# Fix g and get different output (including a posterior sampler):
pn.res <- ebnm_point_normal(x, s, g_init = pn.res, fix_g = TRUE,
                           output = ebnm_output_all())

# Sample from the posterior:
pn.samp <- simulate(pn.res, nsim = 100)
```

```
# Quantiles and HPD confidence intervals can be obtained via sampling:
set.seed(1)
pn.quantiles <- quantile(pn.res, probs = c(0.1, 0.9))
pn.quantiles[1:5, ]
confint(pn.res, level = 0.8, parm = 1:5)

# Examples of usage of control parameter:
# point_normal uses nlm:
pn.res <- ebnm_point_normal(x, s, control = list(print.level = 1))
# unimodal uses mixsqp:
unimodal.res <- ebnm_unimodal(x, s, control = list(verbose = TRUE))
```

ebnm_add_sampler	<i>Add sampler to an ebnm_object</i>
------------------	--------------------------------------

Description

Adds a posterior sampler to a fitted [ebnm](#) object.

Usage

```
ebnm_add_sampler(ebnm_res)
```

Arguments

`ebnm_res` The fitted ebnm object.

Value

The ebnm object with an additional field `posterior_sampler`.

ebnm_ash	<i>Solve the EBNM problem using an ash family of distributions</i>
----------	--

Description

A wrapper to function [ash](#) in package `ashr`. Identical to function [ebnm](#) with argument `prior_family = "ash"`.

Usage

```
ebnm_ash(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	Passed to ash as parameter <code>mode</code> .
<code>scale</code>	Passed to ash as parameter <code>mixsd</code> .
<code>g_init</code>	Passed to ash as parameter <code>g</code> .
<code>fix_g</code>	Passed to ash as parameter <code>fixg</code> .
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	Passed to ash as parameter <code>control</code> .
<code>...</code>	Additional parameters to be passed to ash .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

- `data` A data frame containing the observations `x` and standard errors `s`.
- `posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).
- `fitted_g` The fitted prior $\hat{g}$.
- `log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.
- `posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_deconvolver	<i>Solve the EBNM problem using the "deconvolveR" family of distributions</i>
------------------	---

Description

Solves the empirical Bayes normal means (EBNM) problem using a non-parametric exponential family with a natural spline basis. Like [ebnm_npmle](#), there is no unimodal assumption, but whereas [ebnm_npmle](#) produces spiky estimates for g , [ebnm_deconvolver](#) estimates are much more regular. See [deconvolveR-package](#) for details and references. Identical to function [ebnm](#) with argument `prior_family = "deconvolver"`.

Usage

```
ebnm_deconvolver(
  x,
  s = 1,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	Standard errors, which must be uniformly equal to 1 (i.e., $s = 1$) since the <code>deconvolveR</code> method takes z -scores as input.
<code>scale</code>	A <code>deconvolveR</code> prior is a finite mixture of point masses

$$\pi_1 \delta_{\mu_1} + \dots + \pi_K \delta_{\mu_K},$$

where parameters π_k are estimated and the point masses are evenly spaced over (μ_1, μ_K) . The distance between successive point masses can be specified by the user via parameter `scale`, in which case the argument should be a scalar specifying the distance $d = \mu_2 - \mu_1 = \dots = \mu_K - \mu_{K-1}$; alternatively, if `scale = "estimate"`, then `ebnm` sets the grid via function [ebnm_scale_npmle](#).

<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the scale parameter. When supplied, <code>g_init</code> should be an object of class <code>normalmix</code> or an <code>ebnm</code> object in which the fitted prior is an object of class <code>normalmix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to optimization function <code>nlm</code> .
<code>...</code>	Additional parameters to be passed to function <code>deconv</code> in package <code>deconvolveR</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See `ebnm` for examples of usage and model details.

Available S3 methods include `coef.ebnm`, `confint.ebnm`, `fitted.ebnm`, `logLik.ebnm`, `nobs.ebnm`, `plot.ebnm`, `predict.ebnm`, `print.ebnm`, `print.summary.ebnm`, `quantile.ebnm`, `residuals.ebnm`, `simulate.ebnm`, `summary.ebnm`, and `vcov.ebnm`.

`ebnm_flat`

Solve the EBNM problem using a flat prior

Description

Solves the empirical Bayes normal means (EBNM) problem using a "non-informative" improper uniform prior, which yields posteriors

$$\theta_j | x_j, s_j \sim N(x_j, s_j^2).$$

Identical to function `ebnm` with argument `prior_family = "flat"`. For details about the model, see `ebnm`.

Usage

```
ebnm_flat(
  x,
  s = 1,
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default()
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>g_init</code>	Not used by <code>ebnm_flat</code> , but included for consistency with other <code>ebnm</code> functions.
<code>fix_g</code>	Not used by <code>ebnm_flat</code> , but included for consistency with other <code>ebnm</code> functions.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations `x` and standard errors `s`.

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_generalized_binary

Solve the EBNM problem using generalized binary priors

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of nonnegative distributions consisting of mixtures where one component is a point mass at zero and the other is a truncated normal distribution with lower bound zero and nonzero mode. Typically, the mode is positive, with the ratio of the mode to the standard deviation taken to be large, so that posterior estimates are strongly shrunk towards one of two values (zero or the mode of the normal component). Identical to function [ebnm](#) with argument `prior_family = "generalized_binary"`. For details, see Liu et al. (2023), cited in **References** below.

Usage

```
ebnm_generalized_binary(
  x,
  s = 1,
  mode = "estimate",
  scale = 0.1,
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the truncated normal component, or "estimate" if the mode is to be estimated from the data (the location of the point mass is fixed at zero).
<code>scale</code>	A scalar specifying the ratio of the (untruncated) standard deviation of the normal component to its mode. This ratio must be fixed in advance (i.e., it is not possible to set <code>scale = "estimate"</code> when using generalized binary priors).
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class tnormalmix or an <code>ebnm</code> object in which the fitted prior is an object of class <code>tnormalmix</code> .

<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to function <code>optim</code> , where method has been set to "L-BFGS-B".
<code>...</code>	The following additional arguments act as control parameters for the outer EM loops in the fitting algorithm. Each loop iteratively updates parameters w (the mixture proportion corresponding to the truncated normal component) and μ (the mode of the truncated normal component):
<code>wlist</code>	A vector defining intervals of w for which optimal solutions will separately be found. For example, if <code>wlist = c(0, 0.5, 1)</code> , then two optimal priors will be found: one such that w is constrained to be less than 0.5 and one such that it is constrained to be greater than 0.5.
<code>maxiter</code>	A scalar specifying the maximum number of iterations to perform in each outer EM loop.
<code>tol</code>	A scalar specifying the convergence tolerance parameter for each outer EM loop.
<code>mu_init</code>	A scalar specifying the initial value of μ to be used in each outer EM loop.
<code>mu_range</code>	A vector of length two specifying lower and upper bounds for possible values of μ .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

- `data` A data frame containing the observations x and standard errors s .
- `posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).
- `fitted_g` The fitted prior $\hat{g}$.
- `log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.
- `posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

References

Yusha Liu, Peter Carbonetto, Jason Willwerscheid, Scott A Oakes, Kay F Macleod, and Matthew Stephens (2023). Dissecting tumor transcriptional heterogeneity from single-cell RNA-seq data by generalized binary covariance decomposition. *bioRxiv* 2023.08.15.553436.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

 ebnm_group

Solve the EBNM problem for grouped data

Description

Solves the empirical Bayes normal means (EBNM) problem for observations belonging to distinct groups.

Usage

```
ebnm_group(
  x,
  s = 1,
  group,
  prior_family = "point_normal",
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  ...
)
```

Arguments

- | | |
|--------------|--|
| x | A vector of observations. Missing observations (NAs) are not allowed. |
| s | A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed. Two prior families have additional restrictions: when horseshoe priors are used, errors must be homoskedastic; and since function deconv in package deconvolveR takes z -scores, the "deconvolver" family requires that all standard errors be equal to 1. |
| group | A vector of character strings that gives the group to which each observation belongs. It must have the same length as argument x. For an example of usage, see Examples below. |
| prior_family | A named vector that specifies the prior family G for each group. If the same prior family is to be used for all groups, then a character string may be used instead. |

mode	A named list that specifies, for each group, the mode of the respective prior g , or "estimate" if the mode is to be estimated from the data. If the mode is the same across groups, then a scalar may be used instead. If all modes are to be estimated, then mode = "estimate" may be used.
scale	A named list that specifies, for each group, the scale parameter(s) of the respective prior, or "estimate" if the scale parameters are to be estimated from the data. If the scale parameter is the same across groups, then a scalar may be used instead. If all scales are to be estimated, then scale = "estimate" may be used.
g_init	The prior distributions g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with fix_g = TRUE to fix the prior (useful, for example, to do computations with the "true" g in simulations). If g_init is specified but fix_g = FALSE, g_init specifies the initial value of g used during optimization. If g_init is supplied, it should be a named list that specifies, for each group, a prior of the appropriate class (normalmix for normal, point-normal, scale mixture of normals, and deconvolveR prior families, as well as for the NPMLE; class laplacemix for point-Laplace families; class gammamix for point-exponential families; class horseshoe for horseshoe families; and class unimix for unimodal_ families).
fix_g	If TRUE, fix the prior g at g_init instead of estimating it.
output	A character vector indicating which values are to be returned. Function ebnm_output_default() provides the default return values, while ebnm_output_all() lists all possible return values. See Value below.
...	Additional parameters. When a unimodal_ prior family is used, these parameters are passed to function ash in package ashr . Although it does not call into ashr , the scale mixture of normals family accepts parameter gridmult for purposes of comparison. When gridmult is set, an ashr -style grid will be used instead of the default ebnm grid. When the "deconvolver" family is used, additional parameters are passed to function deconv in package deconvolveR . Families of generalized binary priors take several additional parameters; see ebnm_generalized_binary . In all other cases, additional parameters are ignored.

Details

The EBNM model for grouped data, with observations x_j belonging to groups $k = 1, \dots, K$, is

$$x_j | \theta_j, s_j \sim N(\theta_j, s_j^2)$$

$$\theta_j \sim g_{k(j)} \in G_{k(j)}.$$

Solving the EBNM problem for grouped data is equivalent to solving a separate EBNM problem for each group $k = 1, \dots, K$, with the optimal log likelihood equal to the sum of the optimal log likelihoods for each separate problem.

Value

An ebnm object. Depending on the argument to output, the object is a list containing elements:

data A data frame containing the observations x and standard errors s .

posterior A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

fitted_g The fitted prior $\hat{g}$ (an object of class [normalmix](#), [laplacemix](#), [gammamix](#), [unimix](#), [tnormalmix](#), or [horseshoe](#)).

log_likelihood The optimal log likelihood attained, $L(\hat{g})$.

posterior_sampler A function that can be used to produce samples from the posterior. For all prior families other than the horseshoe, the sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation. Since `ebnm_horseshoe` returns an MCMC sampler, it additionally takes parameter `burn`, the number of burn-in samples to discard.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

[ebnm](#)

Examples

```
group <- c(rep("small_sd", 100), rep("large_sd", 100))
theta <- c(rnorm(100, sd = 1), rnorm(100, sd = 10))
s <- 1
x <- theta + rnorm(200, 0, s)

ebnm.group.res <- ebnm_group(x, s, group)

# Use different prior families for each group:
ebnm.group.res <- ebnm_group(
  x, s, group,
  prior_family = list(small_sd = "normal", large_sd = "normal_scale_mixture")
)

# Different modes and scales can be set similarly:
ebnm.group.res <- ebnm_group(
  x, s, group,
  mode = list(small_sd = 0, large_sd = "estimate"),
  scale = list(small_sd = 1, large_sd = "estimate")
)
```

`ebnm_horseshoe`

Solve the EBNM problem using horseshoe priors

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of [horseshoe](#) distributions. Identical to function [ebnm](#) with argument `prior_family = "horseshoe"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_horseshoe(
  x,
  s = 1,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A <i>scalar</i> specifying the standard error of the observations (observations must be homoskedastic).
<code>scale</code>	A scalar corresponding to $s\tau$ in the usual parametrization of the horseshoe distribution, or "estimate" if this parameter is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class horseshoe or an <code>ebnm</code> object in which the fitted prior is an object of class <code>horseshoe</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to function optimize .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations `x` and standard errors `s`.

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The function takes parameters `nsamp`, the number of posterior samples to return per observation, and `burn`, the number of burn-in samples to discard (an MCMC sampler is used).

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

 ebnm_normal

Solve the EBNM problem using normal priors

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of normal distributions. Identical to function [ebnm](#) with argument `prior_family = "normal"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_normal(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	A scalar specifying the standard deviation of the normal prior or "estimate" if the standard deviation is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class normalmix or an ebnm object in which the fitted prior is an object of class normalmix .

<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>optmethod</code>	A string specifying which optimization function is to be used. Options include "nlm", "lbfgsb" (which calls <code>optim</code> with <code>method = "L-BFGS-B"</code>), and "trust" (which calls into package <code>trust</code>). Other options are "nohess_nlm", "nograd_nlm", and "nograd_lbfgsb", which use numerical approximations rather than exact expressions for the Hessian and (for the latter two) the gradient. The default option is "nohess_nlm".
<code>control</code>	A list of control parameters to be passed to the optimization function specified by parameter <code>optmethod</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

`ebnm_normal_scale_mixture`

Solve the EBNM problem using scale mixtures of normals

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of scale mixtures of normals. Identical to function [ebnm](#) with argument `prior_family = "normal_scale_mixture"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_normal_scale_mixture(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

x	A vector of observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
mode	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
scale	The nonparametric family of scale mixtures of normals is approximated via a finite mixture of normal distributions $\pi_1 N(\mu, \sigma_1^2) + \dots + \pi_K N(\mu, \sigma_K^2),$ where parameters π_k are estimated and the grid of standard deviations $(\sigma_1, \dots, \sigma_K)$ is fixed in advance. By making the grid sufficiently dense, one can obtain an arbitrarily good approximation. The grid can be specified by the user via parameter <code>scale</code> , in which case the argument should be the vector of standard deviations $(\sigma_1, \dots, \sigma_K)$; alternatively, if <code>scale = "estimate"</code> , then <code>ebnm</code> sets the grid via function ebnm_scale_normalmix . Note that <code>ebnm</code> sets the grid differently from function ash . To use the <code>ash</code> grid, set <code>scale = "estimate"</code> and pass in <code>gridmult</code> as an additional parameter. See ash for defaults and details.
g_init	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the mode and scale parameters. When supplied, <code>g_init</code> should be an object of class normalmix or an <code>ebnm</code> object in which the fitted prior is an object of class <code>normalmix</code> .
fix_g	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
output	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
control	A list of control parameters to be passed to optimization function mixsqp .
...	When parameter <code>gridmult</code> is set, an ash -style grid will be used instead of the default <code>ebnm</code> grid (see parameter <code>scale</code> above). Other additional parameters are ignored.

Value

An ebnm object. Depending on the argument to output, the object is a list containing elements:

`data` A data frame containing the observations `x` and standard errors `s`.

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for ebnm objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_npmle

Solve the EBNM problem using the family of all distributions

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of all distributions. Identical to function [ebnm](#) with argument `prior_family = "npmle"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_npmle(
  x,
  s = 1,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL
)
```

Arguments

x	A vector of observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
scale	The nonparametric family of all distributions is approximated via a finite mixture of point masses $\pi_1 \delta_{\mu_1} + \dots + \pi_K \delta_{\mu_K},$ where parameters π_k are estimated and the point masses are evenly spaced over (μ_1, μ_K). By taking a sufficiently dense grid of point masses, one can obtain an arbitrarily good approximation. The distance between successive point masses can be specified by the user via parameter <code>scale</code>, in which case the argument should be a scalar specifying the distance $d = \mu_2 - \mu_1 = \dots = \mu_K - \mu_{K-1}$; alternatively, if <code>scale = "estimate"</code>, then <code>ebnm</code> sets the grid via function ebnm_scale_npmle.
g_init	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the <code>scale</code> parameter. When supplied, <code>g_init</code> should be an object of class normalmix or an <code>ebnm</code> object in which the fitted prior is an object of class <code>normalmix</code> .
fix_g	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
output	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
optmethod	Not used by <code>ebnm_npmle</code> .
control	A list of control parameters to be passed to optimization function mixsqp .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

- `data` A data frame containing the observations `x` and standard errors `s`.
- `posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).
- `fitted_g` The fitted prior $\hat{g}$.
- `log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.
- `posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_point_exponential

Solve the EBNM problem using point-exponential priors

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of point-exponential priors (the family of mixtures where one component is a point mass at μ and the other is a (nonnegative) exponential distribution with mode μ). Identical to function [ebnm](#) with argument `prior_family = "point_exponential"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_point_exponential(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	A scalar specifying the scale parameter of the exponential component or "estimate" if the scale is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of

	class gammamix or an <code>ebnm</code> object in which the fitted prior is an object of class <code>gammamix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>optmethod</code>	A string specifying which optimization function is to be used. Options include "nlm", "lbfgsb" (which calls <code>optim</code> with <code>method = "L-BFGS-B"</code>), and "trust" (which calls into package <code>trust</code>). Other options are "nohess_nlm", "nograd_nlm", and "nograd_lbfgsb", which use numerical approximations rather than exact expressions for the Hessian and (for the latter two) the gradient. The default option is "nohess_nlm".
<code>control</code>	A list of control parameters to be passed to the optimization function specified by parameter <code>optmethod</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include `coef.ebnm`, `confint.ebnm`, `fitted.ebnm`, `logLik.ebnm`, `nobs.ebnm`, `plot.ebnm`, `predict.ebnm`, `print.ebnm`, `print.summary.ebnm`, `quantile.ebnm`, `residuals.ebnm`, `simulate.ebnm`, `summary.ebnm`, and `vcov.ebnm`.

ebnm_point_laplace *Solve the EBNM problem using point-Laplace priors*

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of point-Laplace priors (the family of mixtures where one component is a point mass at μ and the other is a double-exponential distribution centered at μ). Identical to function [ebnm](#) with argument `prior_family = "point_laplace"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_point_laplace(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	A scalar specifying the scale parameter of the Laplace component or "estimate" if the scale is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class laplacemix or an <code>ebnm</code> object in which the fitted prior is an object of class <code>laplacemix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.

optmethod	A string specifying which optimization function is to be used. Options include "nlm", "lbfgsb" (which calls optim with method = "L-BFGS-B"), and "trust" (which calls into package trust). Other options are "nohess_nlm", "nograd_nlm", and "nograd_lbfgsb", which use numerical approximations rather than exact expressions for the Hessian and (for the latter two) the gradient. The default option is "nohess_nlm".
control	A list of control parameters to be passed to the optimization function specified by parameter optmethod.

Value

An ebnm object. Depending on the argument to output, the object is a list containing elements:

data A data frame containing the observations x and standard errors s .

posterior A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

fitted_g The fitted prior $\hat{g}$.

log_likelihood The optimal log likelihood attained, $L(\hat{g})$.

posterior_sampler A function that can be used to produce samples from the posterior. The sampler takes a single parameter nsamp, the number of posterior samples to return per observation.

S3 methods coef, confint, fitted, logLik, nobs, plot, predict, print, quantile, residuals, simulate, summary, and vcov have been implemented for ebnm objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_point_mass

Solve the EBNM problem using a point mass prior

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of point masses δ_μ . Posteriors are simply point masses at μ . Identical to function [ebnm](#) with argument prior_family = "point_mass". For details about the model, see [ebnm](#).

Usage

```
ebnm_point_mass(
  x,
  s = 1,
  mode = 0,
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default()
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the location of the point mass or "estimate" if the location is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class <code>normalmix</code> or an <code>ebnm</code> object in which the fitted prior is an object of class <code>normalmix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations `x` and standard errors `s`.

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_point_normal	<i>Solve the EBNM problem using point-normal priors</i>
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Description

Solves the empirical Bayes normal means (EBNM) problem using the family of point-normal priors (the family of mixtures where one component is a point mass at μ and the other is a normal distribution centered at μ). Identical to function [ebnm](#) with argument `prior_family = "point_normal"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_point_normal(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  optmethod = NULL,
  control = NULL
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	A scalar specifying the standard deviation of the normal component or "estimate" if the standard deviation is to be estimated from the data.
<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. When supplied, <code>g_init</code> should be an object of class normalmix or an ebnm object in which the fitted prior is an object of class normalmix .

fix_g	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
output	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
optmethod	A string specifying which optimization function is to be used. Options include "nlm", "lbfgsb" (which calls <code>optim</code> with <code>method = "L-BFGS-B"</code>), and "trust" (which calls into package <code>trust</code>). Other options are "nohess_nlm", "nograd_nlm", and "nograd_lbfgsb", which use numerical approximations rather than exact expressions for the Hessian and (for the latter two) the gradient. The default option is "nohess_nlm".
control	A list of control parameters to be passed to the optimization function specified by parameter <code>optmethod</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

`ebnm_scale_normalmix` *Set scale parameter for scale mixtures of normals*

Description

The default method for setting the scale parameter for function [ebnm_normal_scale_mixture](#).

Usage

```
ebnm_scale_normalmix(
  x,
  s,
  mode = 0,
  min_K = 3,
  max_K = 300,
  KLdiv_target = 1/length(x)
)
```

Arguments

x	A vector of observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
mode	A scalar specifying the mode of the prior g .
min_K	The minimum number of components K to include in the finite mixture of normal distributions used to approximate the nonparametric family of scale mixtures of normals.
max_K	The maximum number of components K to include in the approximating mixture of normal distributions.
KLdiv_target	The desired bound κ on the KL-divergence from the solution obtained using the approximating mixture to the exact solution. More precisely, the scale parameter is set such that given the exact MLE

$$\hat{g} := \operatorname{argmax}_{g \in G} L(g),$$

where G is the full nonparametric family, and given the MLE for the approximating family $\tilde{G}$

$$\tilde{g} := \operatorname{argmax}_{g \in \tilde{G}} L(g),$$

we have that

$$\text{KL}(\hat{g} * N(0, s^2) \mid \tilde{g} * N(0, s^2)) \leq \kappa,$$

where $* N(0, s^2)$ denotes convolution with the normal error distribution (the derivation of the bound assumes homoskedastic observations). For details, see **References** below.

References

Jason Willwerscheid (2021). *Empirical Bayes Matrix Factorization: Methods and Applications*. University of Chicago, PhD dissertation.

ebnm_scale_npmle	<i>Set scale parameter for NPMLE and deconvolveR prior family</i>
------------------	---

Description

The default method for setting the scale parameter for functions [ebnm_npmle](#) and [ebnm_deconvolver](#).

Usage

```
ebnm_scale_npmle(
  x,
  s,
  min_K = 3,
  max_K = 300,
  KLdiv_target = 1/length(x),
  pointmass = TRUE
)
```

Arguments

x	A vector of observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
min_K	The minimum number of components K to include in the mixture of point masses used to approximate the nonparametric family of all distributions.
max_K	The maximum number of components K to include in the approximating mixture of point masses.
KLdiv_target	The desired bound κ on the KL-divergence from the solution obtained using the approximating mixture to the exact solution. More precisely, the scale parameter is set such that given the exact MLE

$$\hat{g} := \operatorname{argmax}_{g \in G} L(g),$$

where G is the full nonparametric family, and given the MLE for the approximating family $\tilde{G}$

$$\tilde{g} := \operatorname{argmax}_{g \in \tilde{G}} L(g),$$

we have that

$$\text{KL}(\hat{g} * N(0, s^2) \mid \tilde{g} * N(0, s^2)) \leq \kappa,$$

where $* N(0, s^2)$ denotes convolution with the normal error distribution (the derivation of the bound assumes homoskedastic observations). For details, see **References** below.

pointmass	When the range of the data is so large that max_K point masses cannot provide a good approximation to the family of all distributions, then ebnm will instead use a mixture of normal distributions, with the standard deviation of each component
-----------	--

equal to $\text{scale}/2$. Setting `pointmass = FALSE` gives the default scale for this mixture of normal distributions.

To be exact, `ebnm` uses a mixture of normal distributions rather than a mixture of point masses when

$$\frac{\max(x) - \min(x)}{\min(s)} > 3 \max_K;$$

for a rationale, see **References** below. Note however that `ebnm` only uses a mixture of normal distributions when `scale = "estimate"`; if parameter `scale` is set manually, then a mixture of point masses will be used in all cases. To use a mixture of normal distributions with the scale set manually, an object created by the constructor function `normalmix` must be provided as argument to parameter `g_init` in function `ebnm_npmle` or function `ebnm_deconvolver`.

References

Jason Willwerscheid (2021). *Empirical Bayes Matrix Factorization: Methods and Applications*. University of Chicago, PhD dissertation.

<code>ebnm_scale_unimix</code>	<i>Set scale parameter for nonparametric unimodal prior families</i>
--------------------------------	--

Description

The default method for setting the scale parameter for functions `ebnm_unimodal`, `ebnm_unimodal_symmetric`, `ebnm_unimodal_nonnegative`, and `ebnm_unimodal_nonpositive`.

Usage

```
ebnm_scale_unimix(
  x,
  s,
  mode = 0,
  min_K = 3,
  max_K = 300,
  KLdiv_target = 1/length(x)
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g .
<code>min_K</code>	The minimum number of components K to include in the finite mixture of uniform distributions used to approximate the nonparametric family of unimodal distributions.

max_K	The maximum number of components K to include in the approximating mixture of uniform distributions.
KLdiv_target	The desired bound κ on the KL-divergence from the solution obtained using the approximating mixture to the exact solution. More precisely, the scale parameter is set such that given the exact MLE

$$\hat{g} := \operatorname{argmax}_{g \in G} L(g),$$

where G is the full nonparametric family, and given the MLE for the approximating family $\tilde{G}$

$$\tilde{g} := \operatorname{argmax}_{g \in \tilde{G}} L(g),$$

we have that

$$\text{KL}(\hat{g} * N(0, s^2) \mid \tilde{g} * N(0, s^2)) \leq \kappa,$$

where $* N(0, s^2)$ denotes convolution with the normal error distribution (the derivation of the bound assumes homoskedastic observations). For details, see **References** below.

References

Jason Willwerscheid (2021). *Empirical Bayes Matrix Factorization: Methods and Applications*. University of Chicago, PhD dissertation.

ebnm_unimodal

Solve the EBNM problem using unimodal distributions

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of all unimodal distributions. Identical to function [ebnm](#) with argument `prior_family = "unimodal"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_unimodal(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

x	A vector of observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
mode	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
scale	The nonparametric family of unimodal distributions is approximated via a finite mixture of uniform distributions $\pi_1^l \text{Unif}(\mu - a_1, \mu) + \pi_1^u \text{Unif}(\mu, \mu + a_1) + \dots + \pi_K^l \text{Unif}(\mu - a_K, \mu) + \pi_K^u \text{Unif}(\mu, \mu + a_K),$ where parameters π_k^l and π_k^u are estimated and the grid of lengths $(a_1, \dots, a_K)$ is fixed in advance. By making the grid sufficiently dense, one can obtain an arbitrarily good approximation. The grid can be specified by the user via parameter scale, in which case the argument should be the vector of lengths $(a_1, \dots, a_K)$; alternatively, if scale = "estimate", then ebnm sets the grid via function ebnm_scale_unimix . Note that ebnm sets the grid differently from function ash . To use the ash grid, set scale = "estimate" and pass in gridmult as an additional parameter. See ash for defaults and details.
g_init	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with fix_g = TRUE to fix the prior (useful, for example, to do computations with the "true" g in simulations). If g_init is specified but fix_g = FALSE, g_init specifies the initial value of g used during optimization. This has the side effect of fixing the mode and scale parameters. When supplied, g_init should be an object of class unimix or an ebnm object in which the fitted prior is an object of class unimix.
fix_g	If TRUE, fix the prior g at g_init instead of estimating it.
output	A character vector indicating which values are to be returned. Function ebnm_output_default() provides the default return values, while ebnm_output_all() lists all possible return values. See Value below.
control	A list of control parameters to be passed to optimization function mixsqp .
...	Additional parameters to be passed to function ash in package ash.

Value

An ebnm object. Depending on the argument to output, the object is a list containing elements:

data A data frame containing the observations x and standard errors s .
posterior A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).
fitted_g The fitted prior $\hat{g}$.
log_likelihood The optimal log likelihood attained, $L(\hat{g})$.
posterior_sampler A function that can be used to produce samples from the posterior. The sampler takes a single parameter nsamp, the number of posterior samples to return per observation.
S3 methods coef, confint, fitted, logLik, nobs, plot, predict, print, quantile, residuals, simulate, summary, and vcov have been implemented for ebnm objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

ebnm_unimodal_nonnegative

Solve the EBNM problem using unimodal nonnegative distributions

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of unimodal distributions with support constrained to be greater than the mode. Identical to function [ebnm](#) with argument `prior_family = "unimodal_nonnegative"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_unimodal_nonnegative(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	The nonparametric family of nonnegative unimodal distributions is approximated via a finite mixture of uniform distributions

$$\pi_1 \text{Unif}(\mu, \mu + a_1) + \dots + \pi_K \text{Unif}(\mu, \mu + a_K),$$

where parameters π_k are estimated and the grid of lengths $(a_1, \dots, a_K)$ is fixed in advance. By making the grid sufficiently dense, one can obtain an arbitrarily good approximation. The grid can be specified by the user via parameter `scale`,

in which case the argument should be the vector of lengths $(a_1, \dots, a_K)$; alternatively, if `scale = "estimate"`, then `ebnm` sets the grid via function `ebnm_scale_unimix`. Note that `ebnm` sets the grid differently from function `ash`. To use the `ash` grid, set `scale = "estimate"` and pass in `gridmult` as an additional parameter. See `ash` for defaults and details.

<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the mode and scale parameters. When supplied, <code>g_init</code> should be an object of class <code>unimix</code> or an <code>ebnm</code> object in which the fitted prior is an object of class <code>unimix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to optimization function <code>mixsqp</code> .
<code>...</code>	Additional parameters to be passed to function <code>ash</code> in package <code>ashr</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See `ebnm` for examples of usage and model details.

Available S3 methods include `coef.ebnm`, `confint.ebnm`, `fitted.ebnm`, `logLik.ebnm`, `nobs.ebnm`, `plot.ebnm`, `predict.ebnm`, `print.ebnm`, `print.summary.ebnm`, `quantile.ebnm`, `residuals.ebnm`, `simulate.ebnm`, `summary.ebnm`, and `vcov.ebnm`.

ebnm_unimodal_nonpositive

Solve the EBNM problem using unimodal nonpositive distributions

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of unimodal distributions with support constrained to be less than the mode. Identical to function [ebnm](#) with argument `prior_family = "unimodal_nonpositive"`. For details about the model, see [ebnm](#).

Usage

```
ebnm_unimodal_nonpositive(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	The nonparametric family of nonnegative unimodal distributions is approximated via a finite mixture of uniform distributions

$$\pi_1 \text{Unif}(\mu - a_1, \mu) + \dots + \pi_K \text{Unif}(\mu - a_K, \mu),$$

where parameters π_k are estimated and the grid of lengths $(a_1, \dots, a_K)$ is fixed in advance. By making the grid sufficiently dense, one can obtain an arbitrarily good approximation. The grid can be specified by the user via parameter `scale`, in which case the argument should be the vector of lengths $(a_1, \dots, a_K)$; alternatively, if `scale = "estimate"`, then `ebnm` sets the grid via function [ebnm_scale_unimix](#). Note that `ebnm` sets the grid differently from function [ash](#). To use the `ash` grid, set `scale = "estimate"` and pass in `gridmult` as an additional parameter. See [ash](#) for defaults and details.

<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the mode and scale parameters. When supplied, <code>g_init</code> should be an object of class <code>unimix</code> or an <code>ebnm</code> object in which the fitted prior is an object of class <code>unimix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to optimization function <code>mixsqp</code> .
<code>...</code>	Additional parameters to be passed to function <code>ash</code> in package <code>ashr</code> .

Value

An `ebnm` object. Depending on the argument to `output`, the object is a list containing elements:

`data` A data frame containing the observations x and standard errors s .

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for `ebnm` objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See `ebnm` for examples of usage and model details.

Available S3 methods include `coef.ebnm`, `confint.ebnm`, `fitted.ebnm`, `logLik.ebnm`, `nobs.ebnm`, `plot.ebnm`, `predict.ebnm`, `print.ebnm`, `print.summary.ebnm`, `quantile.ebnm`, `residuals.ebnm`, `simulate.ebnm`, `summary.ebnm`, and `vcov.ebnm`.

`ebnm_unimodal_symmetric`

Solve the EBNM problem using symmetric unimodal distributions

Description

Solves the empirical Bayes normal means (EBNM) problem using the family of symmetric unimodal distributions. Identical to function `ebnm` with argument `prior_family = "unimodal_symmetric"`. For details about the model, see `ebnm`.

Usage

```
ebnm_unimodal_symmetric(
  x,
  s = 1,
  mode = 0,
  scale = "estimate",
  g_init = NULL,
  fix_g = FALSE,
  output = ebnm_output_default(),
  control = NULL,
  ...
)
```

Arguments

<code>x</code>	A vector of observations. Missing observations (NAs) are not allowed.
<code>s</code>	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed.
<code>mode</code>	A scalar specifying the mode of the prior g or "estimate" if the mode is to be estimated from the data.
<code>scale</code>	The nonparametric family of symmetric unimodal distributions is approximated via a finite mixture of uniform distributions

$$\pi_1 \text{Unif}(\mu - a_1, \mu + a_1) + \dots + \pi_K \text{Unif}(\mu - a_K, \mu + a_K),$$

where parameters π_k are estimated and the grid of (half-)lengths $(a_1, \dots, a_K)$ is fixed in advance. By making the grid sufficiently dense, one can obtain an arbitrarily good approximation. The grid can be specified by the user via parameter `scale`, in which case the argument should be the vector $(a_1, \dots, a_K)$; alternatively, if `scale = "estimate"`, then `ebnm` sets the grid via function `ebnm_scale_unimix`. Note that `ebnm` sets the grid differently from function `ash`. To use the `ash` grid, set `scale = "estimate"` and pass in `gridmult` as an additional parameter. See `ash` for defaults and details.

<code>g_init</code>	The prior distribution g . Usually this is left unspecified (NULL) and estimated from the data. However, it can be used in conjunction with <code>fix_g = TRUE</code> to fix the prior (useful, for example, to do computations with the "true" g in simulations). If <code>g_init</code> is specified but <code>fix_g = FALSE</code> , <code>g_init</code> specifies the initial value of g used during optimization. This has the side effect of fixing the mode and scale parameters. When supplied, <code>g_init</code> should be an object of class <code>unimix</code> or an <code>ebnm</code> object in which the fitted prior is an object of class <code>unimix</code> .
<code>fix_g</code>	If TRUE, fix the prior g at <code>g_init</code> instead of estimating it.
<code>output</code>	A character vector indicating which values are to be returned. Function <code>ebnm_output_default()</code> provides the default return values, while <code>ebnm_output_all()</code> lists all possible return values. See Value below.
<code>control</code>	A list of control parameters to be passed to optimization function <code>mixsqp</code> .
<code>...</code>	Additional parameters to be passed to function <code>ash</code> in package <code>ashr</code> .

Value

An ebnm object. Depending on the argument to output, the object is a list containing elements:

`data` A data frame containing the observations `x` and standard errors `s`.

`posterior` A data frame of summary results (posterior means, standard deviations, second moments, and local false sign rates).

`fitted_g` The fitted prior $\hat{g}$.

`log_likelihood` The optimal log likelihood attained, $L(\hat{g})$.

`posterior_sampler` A function that can be used to produce samples from the posterior. The sampler takes a single parameter `nsamp`, the number of posterior samples to return per observation.

S3 methods `coef`, `confint`, `fitted`, `logLik`, `nobs`, `plot`, `predict`, `print`, `quantile`, `residuals`, `simulate`, `summary`, and `vcov` have been implemented for ebnm objects. For details, see the respective help pages, linked below under **See Also**.

See Also

See [ebnm](#) for examples of usage and model details.

Available S3 methods include [coef.ebnm](#), [confint.ebnm](#), [fitted.ebnm](#), [logLik.ebnm](#), [nobs.ebnm](#), [plot.ebnm](#), [predict.ebnm](#), [print.ebnm](#), [print.summary.ebnm](#), [quantile.ebnm](#), [residuals.ebnm](#), [simulate.ebnm](#), [summary.ebnm](#), and [vcov.ebnm](#).

`fitted.ebnm`

Extract posterior estimates from a fitted EBNM model

Description

The [fitted](#) method for class [ebnm](#). Returns a data frame that includes posterior means, standard deviations, and local false sign rates (when available).

Usage

```
## S3 method for class 'ebnm'
fitted(object, ...)
```

Arguments

`object` The fitted ebnm object.

`...` Not used. Included for consistency as an S3 method.

gammamix	<i>Constructor for gammamix class</i>
----------	---------------------------------------

Description

Creates a finite mixture of gamma distributions.

Usage

```
gammamix(pi, shape, scale, shift = rep(0, length(pi)))
```

Arguments

pi	A vector of mixture proportions.
shape	A vector of shape parameters.
scale	A vector of scale parameters.
shift	A vector of shift parameters.

Value

An object of class gammamix (a list with elements pi, shape, scale, and shift, described above).

horseshoe	<i>Constructor for horseshoe class</i>
-----------	--

Description

Creates a horseshoe prior (see Carvalho, Polson, and Scott (2010)). The horseshoe is usually parametrized as $\theta_i \sim N(0, s^2 \tau^2 \lambda_i^2)$, $\lambda_i \sim \text{Cauchy}^+(0, 1)$, with s^2 the variance of the error distribution. We use a single parameter scale, which corresponds to $s\tau$ and thus does not depend on the error distribution.

Usage

```
horseshoe(scale)
```

Arguments

scale	The scale parameter (must be a scalar).
-------	---

Value

An object of class horseshoe (a list with a single element scale, described above).

laplacemix	<i>Constructor for laplacemix class</i>
------------	---

Description

Creates a finite mixture of Laplace distributions.

Usage

```
laplacemix(pi, mean, scale)
```

Arguments

pi	A vector of mixture proportions.
mean	A vector of means.
scale	A vector of scale parameters.

Value

An object of class laplacemix (a list with elements pi, mean, and scale, described above).

logLik.ebnm	<i>Extract the log likelihood from a fitted EBNM model</i>
-------------	--

Description

The `logLik` method for class `ebnm`.

Usage

```
## S3 method for class 'ebnm'
logLik(object, ...)
```

Arguments

object	The fitted ebnm object.
...	Not used. Included for consistency as an S3 method.

Value

An object of class logLik, which includes attributes df, the degrees of freedom — i.e., number of parameters in the model —, and nobs, the number of observations in the data.

nobs.ebnm	<i>Get the number of observations used to fit an EBNM model</i>
-----------	---

Description

The `nobs` method for class `ebnm`.

Usage

```
## S3 method for class 'ebnm'
nobs(object, ...)
```

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>...</code>	Not used. Included for consistency as an S3 method.

Value

The number of observations used to fit the `ebnm` object.

<code>plot.ebnm</code>	<i>Plot an <code>ebnm</code> object</i>
------------------------	---

Description

Given one or more fitted `ebnm` object(s), produces a plot of posterior means vs. observations. If desired, a plot of cumulative distribution functions of fitted prior(s) can also be produced.

Usage

```
## S3 method for class 'ebnm'
plot(
  x,
  ...,
  incl_pm = TRUE,
  incl_cdf = FALSE,
  subset = NULL,
  remove_abline = FALSE
)
```

Arguments

<code>x</code>	The fitted <code>ebnm</code> object.
<code>...</code>	Additional <code>ebnm</code> objects to be included on the same plots.
<code>incl_pm</code>	Plot posterior means vs. observations?
<code>incl_cdf</code>	Plot the cumulative distribution functions?
<code>subset</code>	The subset of observations to include on the plot of posterior means vs. observations. Can be a numeric vector corresponding to indices of observations to plot, or a character vector if observations are named. If <code>subset = NULL</code> then all observations will be plotted.
<code>remove_abline</code>	To better illustrate shrinkage effects, the plot of posterior means vs. observations includes the line $y = x$ by default. If <code>remove_abline = TRUE</code> , then this line will not be drawn.

Examples

```

theta <- c(rep(0, 100), rexp(100))
theta[1:50] <- 0
s <- 1
x <- theta + rnorm(200, 0, s)
pn.res <- ebnm_point_normal(x, s)
plot(pn.res)

pe.res <- ebnm_point_exponential(x, s)
plot(pn.res, pe.res)

# Customize plot:
library(ggplot2)
plot(pn.res, pe.res, remove_abline = TRUE) +
  theme_bw() +
  labs(x = "Simulated data")

```

predict.ebnm	<i>Use the estimated prior from a fitted EBNM model to solve the EBNM problem for new data</i>
--------------	--

Description

The `predict` method for class `ebnm`.

Usage

```

## S3 method for class 'ebnm'
predict(object, newdata, s = 1, ...)

```

Arguments

object	The fitted ebnm object.
newdata	A vector of new observations. Missing observations (NAs) are not allowed.
s	A vector of standard errors (or a scalar if all are equal). Standard errors may not be exactly zero, and missing standard errors are not allowed. Two prior families have additional restrictions: when horseshoe priors are used, errors must be homoskedastic; and since function deconv in package deconvolveR takes z -scores, the "deconvolver" family requires that all standard errors be equal to 1.
...	Not used. Included for consistency as an S3 method.

Value

A data frame that includes posterior means, posterior standard deviations, and local false sign rates for the observations in newdata.

print.ebnm	<i>Print an ebnm object</i>
------------	-----------------------------

Description

The print method for class [ebnm](#).

Usage

```
## S3 method for class 'ebnm'
print(x, digits = 2, ...)
```

Arguments

x	The fitted ebnm object.
digits	Number of significant digits to use.
...	Not used. Included for consistency as an S3 method.

print.summary.ebnm	<i>Print a summary.ebnm object</i>
--------------------	------------------------------------

Description

The print method for class `summary.ebnm`.

Usage

```
## S3 method for class 'summary.ebnm'
print(x, digits = 2, ...)
```

Arguments

x	The <code>summary.ebnm</code> object.
digits	Number of significant digits to use.
...	Not used. Included for consistency as an S3 method.

quantile.ebnm	<i>Obtain posterior quantiles using a fitted EBNM model</i>
---------------	---

Description

The `quantile` method for class `ebnm`. Quantiles for posterior distributions $\theta_i \mid x_i, s_i, g$ are estimated via sampling. By default, `ebnm` does not return a posterior sampler; one can be added to the `ebnm` object using function `ebnm_add_sampler`.

Usage

```
## S3 method for class 'ebnm'
quantile(
  x,
  probs = seq(0, 1, 0.25),
  names = TRUE,
  type = 7,
  digits = 7,
  nsim = 1000,
  ...
)
```

Arguments

<code>x</code>	The fitted ebnm object.
<code>probs</code>	numeric vector of probabilities with values in $[0, 1]$. (Values up to '2e-14' outside that range are accepted and moved to the nearby endpoint.)
<code>names</code>	logical; if true, the result has a <code>names</code> attribute. Set to FALSE for speedup with many probs.
<code>type</code>	An integer between 1 and 9 selecting one of the nine quantile algorithms detailed in <code>quantile</code> to be used.
<code>digits</code>	used only when names is true: the precision to use when formatting the percentages. In R versions up to 4.0.x, this had been set to <code>max(2, getOption("digits"))</code> , internally.
<code>nsim</code>	The number of samples to use to estimate quantiles.
<code>...</code>	Additional arguments to be passed to the posterior sampler function. Since <code>ebnm_horseshoe</code> returns an MCMC sampler, it takes parameter burn, the number of burn-in samples to discard. At present, no other samplers take any additional parameters.

Value

A matrix with columns giving quantiles for each posterior $\theta_i \mid x_i, s_i, g$.

<code>residuals.ebnm</code>	<i>Calculate residuals for a fitted EBNM model</i>
-----------------------------	--

Description

The `residuals` method for class `ebnm`. Calculates "residuals" $x_i - \hat{\theta}_i$.

Usage

```
## S3 method for class 'ebnm'
residuals(object, ...)
```

Arguments

<code>object</code>	The fitted ebnm object.
<code>...</code>	Not used. Included for consistency as an S3 method.

simulate.ebnm	<i>Sample from the posterior of a fitted EBNM model</i>
---------------	---

Description

The `simulate` method for class `ebnm`. Extracts the posterior sampler from an object of class `ebnm` and returns a specified number of samples.

Usage

```
## S3 method for class 'ebnm'
simulate(object, nsim = 1, seed = NULL, ...)
```

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>nsim</code>	The number of posterior samples to return per observation.
<code>seed</code>	Either <code>NULL</code> or an integer that will be used in a call to <code>set.seed</code> before simulating. If set, the value is saved as the "seed" attribute of the returned value. The default, <code>NULL</code> , will not change the random generator state.
<code>...</code>	Additional arguments to be passed to the posterior sampler function. Since <code>ebnm_horseshoe</code> returns an MCMC sampler, it takes parameter <code>burn</code> , the number of burn-in samples to discard. At present, no other samplers take any additional parameters.

Value

A matrix of posterior samples, with rows corresponding to distinct samples and columns corresponding to observations.

summary.ebnm	<i>Summarize an ebnm object</i>
--------------	---------------------------------

Description

The summary method for class `ebnm`.

Usage

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

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>...</code>	Not used. Included for consistency as an S3 method.

Value

A `summary.ebnm` object.

<code>vcov.ebnm</code>	<i>Extract posterior variances from a fitted EBNM model</i>
------------------------	---

Description

The `vcov` method for class `ebnm`.

Usage

```
## S3 method for class 'ebnm'
vcov(object, ...)
```

Arguments

<code>object</code>	The fitted <code>ebnm</code> object.
<code>...</code>	Not used. Included for consistency as an S3 method.

<code>wOBA</code>	<i>2022 MLB wOBA Data</i>
-------------------	---------------------------

Description

Weighted on-base average (wOBA) for hitters from the 2022 Major League Baseball (MLB) season. Standard errors are calculated by modeling hitting outcomes as multinomially distributed and plugging in empirical proportions as the “true” outcome probabilities. To handle small sample sizes, standard errors are lower bounded by the errors that would be obtained using league-wide proportions rather than the plug-in estimates.

Format

`wOBA` is a data frame with 688 rows and 6 columns:

FanGraphsID The hitter’s FanGraphs identifier.

Name The hitter’s name.

Team The hitter’s MLB team (given as a three-letter code) or NA if the hitter played for multiple teams.

PA The hitter’s number of plate appearances over the 2022 season.

x The hitter’s wOBA over the 2022 season.

s The standard error for the hitter’s wOBA.

Source

`<https://fangraphs.com>`

Examples

```
data(wOBA)
summary(wOBA)
```

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