

# Package: EvidenceSynthesis (via r-universe)

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**Type** Package

**Title** Synthesizing Causal Evidence in a Distributed Research Network

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**Maintainer** Martijn Schuemie <schuemie@ohdsi.org>

**Description** Routines for combining causal effect estimates and study diagnostics across multiple data sites in a distributed study, without sharing patient-level data. Allows for normal and non-normal approximations of the data-site likelihood of the effect parameter.

**SystemRequirements** Java ( $\geq 8$ )

**Depends** survival, R ( $\geq 3.5.0$ )

**Imports** dplyr, ggplot2, ggdist, gridExtra, meta, EmpiricalCalibration, rJava, BeastJar, Cyclops ( $\geq 3.1.0$ ), HDInterval, coda, rlang, methods

**Suggests** knitr, rmarkdown, testthat, sn

**License** Apache License 2.0

**URL** <https://ohdsi.github.io/EvidenceSynthesis/>,  
<https://github.com/OHDSI/EvidenceSynthesis>

**BugReports** <https://github.com/OHDSI/EvidenceSynthesis/issues>

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---

approximateHierarchicalNormalPosterior

*Approximate Bayesian posterior for hierarchical Normal model*

---

### Description

Approximate a Bayesian posterior from a set of `Cyclops` likelihood profiles under a hierarchical normal model using the Markov chain Monte Carlo engine BEAST.

**Usage**

```
approximateHierarchicalNormalPosterior(
  likelihoodProfiles,
  chainLength = 1100000,
  burnIn = 1e+05,
  subSampleFrequency = 100,
  effectPriorMean = 0,
  effectPriorSd = 0.5,
  nu0 = 1,
  sigma0 = 1,
  effectStartingValue = 0,
  precisionStartingValue = 1,
  seed = 1
)
```

**Arguments**

likelihoodProfiles	List of grid likelihoods profiled with Cyclops.
chainLength	Number of MCMC iterations.
burnIn	Number of MCMC iterations to consider as burn in.
subSampleFrequency	Subsample frequency for the MCMC.
effectPriorMean	Prior mean for global parameter
effectPriorSd	Prior standard deviation for the global parameter
nu0	Prior "sample size" for precision (with precision $\sim \text{gamma}(\text{nu0}/2, \text{nu0}*\text{sigma0}/2)$ )
sigma0	Prior "variance" for precision (with precision $\sim \text{gamma}(\text{nu0}/2, \text{nu0}*\text{sigma0}/2)$ )
effectStartingValue	Initial value for global & local parameter
precisionStartingValue	Initial value for the precision
seed	Seed for the random number generator.

**Value**

A data frame with the point estimates and 95% credible intervals for the the global and local parameter, as well as the global precision. Attributes of the data frame contain the MCMC trace for diagnostics.

**Examples**

```
# TBD
```

---

approximateLikelihood *Approximate a likelihood function*

---

### Description

Approximate the likelihood function using a parametric (normal, skew-normal, or custom parametric), or grid approximation. The approximation does not reveal person-level information, and can therefore be shared among data sites. When counts are low, a normal approximation might not be appropriate.

### Usage

```
approximateLikelihood(
  cyclopsFit,
  parameter = 1,
  approximation = "custom",
  bounds = c(log(0.1), log(10))
)
```

### Arguments

cyclopsFit	A model fitted using the <a href="#">Cyclops::fitCyclopsModel()</a> function.
parameter	The parameter in the cyclopsFit object to profile.
approximation	The type of approximation. Valid options are 'normal', 'skew normal', 'custom', 'grid', or 'adaptive grid'.
bounds	The bounds on the effect size used to fit the approximation.

### Value

A vector of parameters of the likelihood approximation.

### See Also

[computeConfidenceInterval](#), [computeFixedEffectMetaAnalysis](#), [computeBayesianMetaAnalysis](#)

### Examples

```
# Simulate some data for this example:
populations <- simulatePopulations()

cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = populations[[1]],
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
approximation <- approximateLikelihood(cyclopsFit, "x")
approximation
```

```
# (Estimates in this example will vary due to the random simulation)
```

---

```
approximateSimplePosterior
      Approximate simple Bayesian posterior
```

---

### Description

Approximate a Bayesian posterior from a Cyclops likelihood profile and normal prior using the Markov chain Monte Carlo engine BEAST.

### Usage

```
approximateSimplePosterior(
  likelihoodProfile,
  chainLength = 1100000,
  burnIn = 1e+05,
  subSampleFrequency = 100,
  priorMean = 0,
  priorSd = 0.5,
  startingValue = 0,
  seed = 1
)
```

### Arguments

likelihoodProfile	Named vector containing grid likelihood data from Cyclops.
chainLength	Number of MCMC iterations.
burnIn	Number of MCMC iterations to consider as burn in.
subSampleFrequency	Subsample frequency for the MCMC.
priorMean	Prior mean for the regression parameter
priorSd	Prior standard deviation for the regression parameter
startingValue	Initial state for regression parameter
seed	Seed for the random number generator.

### Value

A data frame with the point estimates and 95% credible intervals for the regression parameter. Attributes of the data frame contain the MCMC trace for diagnostics.

**Examples**

```

# Simulate some data for this example:
population <- simulatePopulations(createSimulationSettings(nSites = 1))[[1]]

# Fit a Cox regression at each data site, and approximate likelihood function:
cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = population,
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
likelihoodProfile <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "grid")

# Run MCMC
mcmcTraces <- approximateSimplePosterior(
  likelihoodProfile = likelihoodProfile,
  priorMean = 0, priorSd = 100
)

# Report posterior expectation
mean(mcmcTraces$theta)

# (Estimates in this example will vary due to the random simulation)

```

---

biasCorrectionInference

*Bias Correction with Inference*

---

**Description**

Perform Bayesian posterior inference regarding an outcome of interest with bias correction using negative control analysis. There is an option to not perform bias correction so that un-corrected results can be obtained.

**Usage**

```

biasCorrectionInference(
  likelihoodProfiles,
  ncLikelihoodProfiles = NULL,
  biasDistributions = NULL,
  priorMean = 0,
  priorSd = 1,
  numsamps = 10000,
  thin = 10,
  doCorrection = TRUE,
  seed = 1,
  ...
)

```

**Arguments**

likelihoodProfiles	A list of grid profile likelihoods for the outcome of interest.
ncLikelihoodProfiles	Likelihood profiles for the negative control outcomes. Must be a list of lists of profile likelihoods; if there is only one analysis period, then this must be a length-1 list, with the first item as a list all outcome-wise profile likelihoods.
biasDistributions	Pre-saved bias distribution(s), formatted as the output from <code>fitBiasDistribution()</code> or <code>sequentialFitBiasDistribution()</code> . If NULL, then <code>ncLikelihoodProfiles</code> must be provided.
priorMean	Prior mean for the effect size (log rate ratio).
priorSd	Prior standard deviation for the effect size (log rate ratio).
numsamps	Total number of MCMC samples needed.
thin	Thinning frequency: how many iterations before another sample is obtained?
doCorrection	Whether or not to perform bias correction; default: TRUE.
seed	Seed for the random number generator.
...	Arguments to be passed to <code>sequentialFitBiasDistribution()</code> to fit bias distributions if <code>biasDistributions</code> is NULL.

**Value**

A dataframe with five columns, including posterior median and mean of log RR effect size estimates, 95% credible intervals (`ci95Lb` and `ci95Ub`), posterior probability that log RR > 0 (`p1`), and the period or group ID (`Id`).

It is accompanied by the following attributes:

- `samplesCorrected`: all MCMC samples for the bias corrected log RR effect size estimate.
- `samplesRaw`: all MCMC samples for log RR effect size estimate, without bias correction.
- `biasDistributions`: the learned empirical bias distribution from negative control analysis.
- `summaryRaw`: a summary dataframe (same format as in the main result) without bias correction.
- `corrected`: a logical flag indicating if bias correction has been performed; = TRUE if `doCorrection` = TRUE.

**See Also**

[approximateSimplePosterior](#), [fitBiasDistribution](#)

**Examples**

```
# load example data
data("ncLikelihoods")
data("ooiLikelihoods")
```

```

# perform sequential analysis with bias correction, using the t model
# NOT RUN
# bbcResults = biasCorrectionInference(ooiLikelihoods,
#                                     ncLikelihoodProfiles = ncLikelihoods,
#                                     robust = TRUE,
#                                     seed = 42)

# check out analysis summary
# bbcResults

```

---

```
computeBayesianMetaAnalysis
```

*Compute a Bayesian random-effects meta-analysis*

---

### Description

Compute a Bayesian meta-analysis using the Markov chain Monte Carlo (MCMC) engine BEAST. A normal and half-normal prior are used for the mu and tau parameters, respectively, with standard deviations as defined by the priorSd argument.

### Usage

```

computeBayesianMetaAnalysis(
  data,
  chainLength = 1100000,
  burnIn = 1e+05,
  subSampleFrequency = 100,
  priorSd = c(2, 0.5),
  alpha = 0.05,
  robust = FALSE,
  df = 4,
  seed = 1
)

```

### Arguments

data	A data frame containing either normal, skew-normal, custom parametric, or grid likelihood data, with one row per database.
chainLength	Number of MCMC iterations.
burnIn	Number of MCMC iterations to consider as burn in.
subSampleFrequency	Subsample frequency for the MCMC.
priorSd	A two-dimensional vector with the standard deviation of the prior for mu and tau, respectively.
alpha	The alpha (expected type I error) used for the credible intervals.



robust	Whether or not to use a t-distribution model; default: FALSE.
df	Degrees of freedom for the t-model, only used if robust is TRUE.
seed	The seed for the random number generator.

**Value**

A data frame with the point estimates and 95% credible intervals for the mu and tau parameters (the mean and standard deviation of the distribution from which the per-site effect sizes are drawn). Attributes of the data frame contain the MCMC trace and the detected approximation type.

**See Also**

[approximateLikelihood](#), [computeFixedEffectMetaAnalysis](#)

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
estimate <- computeBayesianMetaAnalysis(approximations)
estimate

# (Estimates in this example will vary due to the random simulation)
```

---

computeConfidenceInterval

*Compute the point estimate and confidence interval given a likelihood function approximation*

---

**Description**

Compute the point estimate and confidence interval given a likelihood function approximation

**Usage**

```
computeConfidenceInterval(approximation, alpha = 0.05)
```

**Arguments**

`approximation` An approximation of the likelihood function as fitted using the `approximateLikelihood()` function.

`alpha` The alpha (expected type I error).

**Details**

Compute the point estimate and confidence interval given a likelihood function approximation.

**Value**

A data frame containing the point estimate, and upper and lower bound of the confidence interval.

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()

cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = populations[[1]],
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
approximation <- approximateLikelihood(cyclopsFit, "x")
computeConfidenceInterval(approximation)
```

---

```
computeFixedEffectMetaAnalysis
```

*Compute a fixed-effect meta-analysis*

---

**Description**

Compute a fixed-effect meta-analysis using a choice of various likelihood approximations.

**Usage**

```
computeFixedEffectMetaAnalysis(data, alpha = 0.05)
```

**Arguments**

`data` A data frame containing either normal, skew-normal, custom parametric, or grid likelihood data. One row per database.

`alpha` The alpha (expected type I error) used for the confidence intervals.

**Value**

The meta-analytic estimate, expressed as the point estimate hazard ratio (rr), its 95 percent confidence interval (lb, ub), as well as the log of the point estimate (logRr), and the standard error (seLogRr).

**See Also**

[approximateLikelihood](#), [computeBayesianMetaAnalysis](#)

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
computeFixedEffectMetaAnalysis(approximations)

# (Estimates in this example will vary due to the random simulation)
```

---

```
createSimulationSettings
```

*Create simulation settings*

---

**Description**

Create an object specifying a simulation. Currently only Cox proportional hazard models are supported.

**Usage**

```
createSimulationSettings(
  nSites = 5,
  n = 10000,
  treatedFraction = 0.2,
```

```

nStrata = 10,
minBackgroundHazard = 2e-07,
maxBackgroundHazard = 2e-05,
hazardRatio = 2,
randomEffectSd = 0
)

```

### Arguments

nSites	Number of database sites to simulate.
n	Number of subjects per site. Either a single number, or a vector of length nSites.
treatedFraction	Fraction of subjects that is treated. Either a single number, or a vector of length nSites.
nStrata	Number of strata per site. Either a single number, or a vector of length nSites.
minBackgroundHazard	Minimum background hazard. Either a single number, or a vector of length nSites.
maxBackgroundHazard	Maximum background hazard. Either a single number, or a vector of length nSites.
hazardRatio	Hazard ratio.
randomEffectSd	Standard deviation of the log(hazardRatio). Fixed effect if equal to 0.

### Value

An object of type `simulationSettings`, to be used in the `simulatePopulations()` function.

### See Also

[simulatePopulations](#)

### Examples

```

settings <- createSimulationSettings(nSites = 1, hazardRatio = 2)
populations <- simulatePopulations(settings)

# Fit a Cox regression for the simulated data site:
cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = populations[[1]],
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
coef(cyclopsFit)

# (Estimates in this example will vary due to the random simulation)

```

---

customFunction	<i>A custom function to approximate a log likelihood function</i>
----------------	---

---

**Description**

A custom function to approximate a log likelihood function

**Usage**

```
customFunction(x, mu, sigma, gamma)
```

**Arguments**

x	The log(hazard ratio) for which to approximate the log likelihood.
mu	The position parameter.
sigma	The scale parameter.
gamma	The skew parameter.

**Details**

A custom parametric function designed to approximate the shape of the Cox log likelihood function. When  $\gamma = 0$  this function is the normal distribution.

**Value**

The approximate log likelihood for the given x.

**Examples**

```
customFunction(x = 0:3, mu = 0, sigma = 1, gamma = 0)
```

---

detectApproximationType	<i>Detect the type of likelihood approximation based on the data format</i>
-------------------------	---

---

**Description**

Detect the type of likelihood approximation based on the data format

**Usage**

```
detectApproximationType(data, verbose = TRUE)
```

**Arguments**

data	The approximation data. Can be a single approximation, or approximations from multiple sites.
verbose	Should the detected type be communicated to the user?

**Value**

A character vector with one of the following values: "normal", "custom", "skew normal", "pooled", "grid", or "adaptive grid".

**Examples**

```
detectApproximationType(data.frame(logRr = 1, seLogRr = 0.1))
```

---

fitBiasDistribution    *Fit Bias Distribution*

---

**Description**

Learn an empirical distribution on estimation bias by simultaneously analyzing a large set of negative control outcomes by a Bayesian hierarchical model through MCMC. Analysis is based on a list of extracted likelihood profiles.

**Usage**

```
fitBiasDistribution(
  likelihoodProfiles,
  priorSds = c(2, 0.5),
  numsamps = 10000,
  thin = 10,
  minNCs = 5,
  robust = FALSE,
  df = 4,
  seed = 1
)
```

**Arguments**

likelihoodProfiles	A list of grid profile likelihoods regarding negative controls.
priorSds	A two-dimensional vector with the standard deviation of the prior for the average bias and the sd/scale parameter, respectively.
numsamps	Total number of MCMC samples needed.
thin	Thinning frequency: how many iterations before another sample is obtained?

minNCs	Minimum number of negative controls needed to fit a bias distribution; default (also recommended): 5.
robust	Whether or not to use a t-distribution model; default: FALSE.
df	Degrees of freedom for the t-model, only used if robust is TRUE.
seed	Seed for the random number generator.

**Value**

A dataframe with three columns and numamps number of rows. Column mean includes MCMC samples for the average bias, scale for the sd/scale parameter, and bias for predictive samples of the bias.

**See Also**

[computeBayesianMetaAnalysis](#)

**Examples**

```
# load example data
data("ncLikelihoods")

# fit a bias distributions by analyzing a set of negative control outcomes
# for example, for the 5th analysis period, and using the t model
# NOT RUN
# biasDistribution = fitBiasDistribution(ncLikelihoods[[5]], robust = TRUE)
```

---

ncLikelihoods	<i>Example profile likelihoods for negative control outcomes</i>
---------------	--

---

**Description**

A list that contain profile likelihoods a large set of negative control outcomes. They are extracted from a real-world observational healthcare database, with the likelihoods profiled using adaptive grids using the Cyclops package.

**Usage**

```
ncLikelihoods
```

**Format**

An object of class list containing 12 lists, where each list includes several dataframes ith column point and value for adaptive grid profile likelihoods.

**References**

Schuemie et al. (2022). Vaccine safety surveillance using routinely collected healthcare data—an empirical evaluation of epidemiological designs. *Frontiers in Pharmacology*.

**Examples**

```
data("ncLikelihoods")
ncLikEx <- ncLikelihoods[["5"]][[1]]

plot(value ~ point, data = ncLikEx)
```

---

ooiLikelihoods

*Example profile likelihoods for a synthetic outcome of interest*

---

**Description**

A list that contain profile likelihoods for a synthetic outcome of interest. They are extracted from a real-world observational healthcare database, with the likelihoods profiled using adaptive grids using the Cyclops package.

**Usage**

```
ooiLikelihoods
```

**Format**

An objects of class `list`; the list contains 12 lists, where each list includes several dataframes with column `point` and `value` for adaptive grid profile likelihoods.

**References**

Schuemie et al. (2022). Vaccine safety surveillance using routinely collected healthcare data—an empirical evaluation of epidemiological designs. *Frontiers in Pharmacology*.

**Examples**

```
data("ooiLikelihoods")
ooiLikEx <- ooiLikelihoods[["5"]][[1]]

plot(value ~ point, data = ooiLikEx)
```



---

plotBiasCorrectionInference  
*Plot bias correction inference*

---

## Description

Plot bias correction inference

## Usage

```
plotBiasCorrectionInference(  
  bbcResult,  
  type = "raw",  
  ids = bbcResult$Id,  
  limits = c(-3, 3),  
  logScale = FALSE,  
  numericId = TRUE,  
  fileName = NULL  
)
```

## Arguments

bbcResult	A (sequential) analysis object generated by the <a href="#">biasCorrectionInference()</a> function.
type	The type of plot. Must be one of <code>c("corrected", "raw", "compare")</code> .
ids	IDs of the periods/groups to plot result for; default is all IDs.
limits	The limits on log RR for plotting.
logScale	Whether or not to show bias in log-RR; default FALSE (shown in RR).
numericId	Whether or not to treat Id as a numeric variable; default: TRUE.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

## Details

Plot empirical bias distributions learned from analyzing negative controls.

## Value

A ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

## See Also

[biasCorrectionInference](#)

**Examples**

```
# Perform sequential analysis using Bayesian bias correction for this example:
data("ncLikelihoods")
data("ooiLikelihoods")
# NOT RUN
# bbcSequential = biasCorrectionInference(ooiLikelihoods, ncLikelihoodProfiles = ncLikelihoods)

# Plot it
# NOT RUN
# plotBiasCorrectionInference(bbcSequential, type = "corrected")
```

---

plotBiasDistribution *Plot bias distributions*

---

**Description**

Plot bias distributions

**Usage**

```
plotBiasDistribution(
  biasDist,
  limits = c(-2, 2),
  logScale = FALSE,
  numericId = TRUE,
  fileName = NULL
)
```

**Arguments**

biasDist	A bias distribution object generated by the <a href="#">fitBiasDistribution()</a> or <a href="#">sequentialFitBiasDistribution()</a> function.
limits	The lower and upper limits in log-RR to plot.
logScale	Whether or not to show bias in log-RR; default FALSE (shown in RR).
numericId	(For sequential or group case only) whether or not to treat Id as a numeric variable; default: TRUE.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

**Details**

Plot empirical bias distributions learned from analyzing negative controls.

**Value**

A ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**See Also**

[fitBiasDistribution](#), [sequentialFitBiasDistribution](#)

**Examples**

```
# Fit a bias distribution for this example:
data("ncLikelihoods")
# NOT RUN
# singleBiasDist = fitBiasDistribution(ncLikelihoods[[5]], seed = 1)

# Plot it
# NOT RUN
# plotBiasDistribution(singleBiasDist)
```

---

plotCovariateBalances *Plot covariate balances*

---

**Description**

Plots the covariate balance before and after matching for multiple data sources.

**Usage**

```
plotCovariateBalances(
  balances,
  labels,
  threshold = 0,
  beforeLabel = "Before matching",
  afterLabel = "After matching",
  fileName = NULL
)
```

**Arguments**

balances	A list of covariate balance objects as created using the <code>computeCovariateBalance()</code> function in the <code>CohortMethod</code> package. Each balance object is expected to be a data frame with at least these two columns: <code>beforeMatchingStdDiff</code> and <code>afterMatchingStdDiff</code> .
labels	A vector containing the labels for the various sources.
threshold	Show a threshold value for the standardized difference.
beforeLabel	Label for before matching / stratification / trimming.
afterLabel	Label for after matching / stratification / trimming.
fileName	Name of the file where the plot should be saved, for example <code>'plot.png'</code> . See the function <a href="#">ggplot2::ggsave</a> for supported file formats.

**Details**

Creates a plot showing the covariate balance before and after matching. Balance distributions are displayed as box plots combined with scatterplots.

**Value**

A Ggplot object. Use the [ggplot2::ggsave](#).

**Examples**

```
# Some example data:
balance1 <- data.frame(
  beforeMatchingStdDiff = rnorm(1000, 0.1, 0.1),
  afterMatchingStdDiff = rnorm(1000, 0, 0.01)
)
balance2 <- data.frame(
  beforeMatchingStdDiff = rnorm(1000, 0.2, 0.1),
  afterMatchingStdDiff = rnorm(1000, 0, 0.05)
)
balance3 <- data.frame(
  beforeMatchingStdDiff = rnorm(1000, 0, 0.1),
  afterMatchingStdDiff = rnorm(1000, 0, 0.03)
)
plotCovariateBalances(
  balances = list(balance1, balance2, balance3),
  labels = c("Site A", "Site B", "Site C")
)
```

---

plotEmpiricalNulls      *Plot empirical null distributions*

---

**Description**

Plot the empirical null distribution for multiple data sources.

**Usage**

```
plotEmpiricalNulls(
  logRr,
  seLogRr,
  labels,
  xLabel = "Relative risk",
  limits = c(0.1, 10),
  showCis = TRUE,
  fileName = NULL
)
```

**Arguments**

logRr	A numeric vector of effect estimates for the negative controls on the log scale.
seLogRr	The standard error of the log of the effect estimates. Hint: often the standard error = $(\log(\text{lower bound 95 percent confidence interval}) - \log(\text{effect estimate}))/qnorm(0.025)$ .
labels	A vector containing the labels for the various sources. Should be of equal length as logRr and seLogRr.
xLabel	The label on the x-axis: the name of the effect estimate.
limits	The limits of the effect size axis.
showCis	Show the 95 percent confidence intervals on the null distribution and distribution parameter estimates?
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave()</a> for supported file formats.

**Details**

Creates a plot showing the empirical null distributions. Distributions are shown as mean plus minus one standard deviation, as well as a distribution plot.

**Value**

A Ggplot object. Use the [ggplot2::ggsave\(\)](#) function to save to file.

**See Also**

[EmpiricalCalibration::fitNull](#), [EmpiricalCalibration::fitMcmcNull](#)

**Examples**

```
# Some example data:
site1 <- EmpiricalCalibration::simulateControls(n = 50, mean = 0, sd = 0.1, trueLogRr = 0)
site1$label <- "Site 1"
site2 <- EmpiricalCalibration::simulateControls(n = 50, mean = 0.1, sd = 0.2, trueLogRr = 0)
site2$label <- "Site 2"
site3 <- EmpiricalCalibration::simulateControls(n = 50, mean = 0.15, sd = 0.25, trueLogRr = 0)
site3$label <- "Site 3"
sites <- rbind(site1, site2, site3)

plotEmpiricalNulls(logRr = sites$logRr, seLogRr = sites$seLogRr, labels = sites$label)
```

---

plotLikelihoodFit      *Plot the likelihood approximation*

---

### Description

Plot the likelihood approximation

### Usage

```
plotLikelihoodFit(  
  approximation,  
  cyclopsFit,  
  parameter = "x",  
  logScale = TRUE,  
  xLabel = "Hazard Ratio",  
  limits = c(0.1, 10),  
  fileName = NULL  
)
```

### Arguments

approximation	An approximation of the likelihood function as fitted using the <a href="#">approximateLikelihood()</a> function.
cyclopsFit	A model fitted using the <a href="#">Cyclops::fitCyclopsModel()</a> function.
parameter	The parameter in the cyclopsFit object to profile.
logScale	Show the y-axis on the log scale?
xLabel	The title of the x-axis.
limits	The limits on the x-axis.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

### Details

Plots the (log) likelihood and the approximation of the likelihood. Allows for reviewing the approximation.

### Value

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**Examples**

```
# Simulate a single database population:
population <- simulatePopulations(createSimulationSettings(nSites = 1))[[1]]

# Approximate the likelihood:
cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = population,
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")

plotLikelihoodFit(approximation, cyclopsFit, parameter = "x")
```

---

plotMcmcTrace

*Plot MCMC trace*


---

**Description**

Plot MCMC trace

**Usage**

```
plotMcmcTrace(
  estimate,
  showEstimate = TRUE,
  dataCutoff = 0.01,
  fileName = NULL
)
```

**Arguments**

estimate	An object as generated using the <a href="#">computeBayesianMetaAnalysis()</a> function.
showEstimate	Show the parameter estimates (mode) and 95 percent confidence intervals?
dataCutoff	This fraction of the data at both tails will be removed.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

**Details**

Plot the samples of the posterior distribution of the mu and tau parameters. Samples are taken using Markov-chain Monte Carlo (MCMC).

**Value**

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**See Also**

[computeBayesianMetaAnalysis](#)

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
estimate <- computeBayesianMetaAnalysis(approximations)
plotMcmcTrace(estimate)
```

---

plotMetaAnalysisForest

*Create a forest plot*

---

**Description**

Creates a forest plot of effect size estimates, including the summary estimate.

**Usage**

```
plotMetaAnalysisForest(
  data,
  labels,
  estimate,
  xLabel = "Relative risk",
  summaryLabel = "Summary",
  limits = c(0.1, 10),
  alpha = 0.05,
  showLikelihood = TRUE,
  fileName = NULL
)
```



**Arguments**

data	A data frame containing either normal, skew-normal, custom parametric, or grid likelihood data. One row per database.
labels	A vector of labels for the data sources.
estimate	The meta-analytic estimate as created using either [ <code>computeFixedEffectMetaAnalysis()</code> ] or [ <code>computeBayesianMetaAnalysis()</code> ] function.
xLabel	The label on the x-axis: the name of the effect estimate.
summaryLabel	The label for the meta-analytic estimate.
limits	The limits of the effect size axis.
alpha	The alpha (expected type I error).
showLikelihood	Show the likelihood curve for each estimate?
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> ifor supported file formats.

**Details**

Creates a forest plot of effect size estimates, including a meta-analysis estimate.

**Value**

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()
labels <- paste("Data site", LETTERS[1:length(populations)])

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
estimate <- computeBayesianMetaAnalysis(approximations)
plotMetaAnalysisForest(approximations, labels, estimate)

# (Estimates in this example will vary due to the random simulation)
```

---

plotPerDbMcmcTrace     *Plot MCMC trace for individual databases*

---

### Description

Plot MCMC trace for individual databases

### Usage

```
plotPerDbMcmcTrace(  
  estimate,  
  showEstimate = TRUE,  
  dataCutoff = 0.01,  
  fileName = NULL  
)
```

### Arguments

estimate	An object as generated using the <a href="#">computeBayesianMetaAnalysis()</a> function.
showEstimate	Show the parameter estimates (mode) and 95 percent confidence intervals?
dataCutoff	This fraction of the data at both tails will be removed.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

### Details

Plot the samples of the posterior distribution of the theta parameter (the estimated log hazard ratio) at each site. Samples are taken using Markov-chain Monte Carlo (MCMC).

### Value

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

### See Also

[computeBayesianMetaAnalysis](#)

### Examples

```
# Simulate some data for this example:  
populations <- simulatePopulations()  
  
# Fit a Cox regression at each data site, and approximate likelihood function:  
fitModelInDatabase <- function(population) {  
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),  
    data = population,  
    modelType = "cox"  
  )  
}
```

```

    cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
    approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
    return(approximation)
  }
  approximations <- lapply(populations, fitModelInDatabase)
  approximations <- do.call("rbind", approximations)

  # At study coordinating center, perform meta-analysis using per-site approximations:
  estimate <- computeBayesianMetaAnalysis(approximations)
  plotPerDbMcmcTrace(estimate)

```

---

plotPerDbPosterior      *Plot posterior density per database*

---

## Description

Plot posterior density per database

## Usage

```

plotPerDbPosterior(
  estimate,
  showEstimate = TRUE,
  dataCutoff = 0.01,
  fileName = NULL
)

```

## Arguments

estimate	An object as generated using the <a href="#">computeBayesianMetaAnalysis()</a> function.
showEstimate	Show the parameter estimates (mode) and 95 percent confidence intervals?
dataCutoff	This fraction of the data at both tails will be removed.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

## Details

Plot the density of the posterior distribution of the theta parameter (the estimated log hazard ratio) at each site.

## Value

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**Examples**

```

# Simulate some data for this example:
populations <- simulatePopulations()

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
estimate <- computeBayesianMetaAnalysis(approximations)
plotPerDbPosterior(estimate)

```

---

plotPosterior

*Plot posterior density*


---

**Description**

Plot posterior density

**Usage**

```

plotPosterior(
  estimate,
  showEstimate = TRUE,
  dataCutoff = 0.01,
  fileName = NULL
)

```

**Arguments**

estimate	An object as generated using the <a href="#">computeBayesianMetaAnalysis()</a> function.
showEstimate	Show the parameter estimates (mode) and 95 percent confidence intervals?
dataCutoff	This fraction of the data at both tails will be removed.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <a href="#">ggplot2::ggsave</a> in the ggplot2 package for supported file formats.

**Details**

Plot the density of the posterior distribution of the mu and tau parameters.

**Value**

A Ggplot object. Use the [ggplot2::ggsave](#) function to save to file.

**See Also**

[computeBayesianMetaAnalysis](#)

**Examples**

```
# Simulate some data for this example:
populations <- simulatePopulations()

# Fit a Cox regression at each data site, and approximate likelihood function:
fitModelInDatabase <- function(population) {
  cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
    data = population,
    modelType = "cox"
  )
  cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
  approximation <- approximateLikelihood(cyclopsFit, parameter = "x", approximation = "custom")
  return(approximation)
}
approximations <- lapply(populations, fitModelInDatabase)
approximations <- do.call("rbind", approximations)

# At study coordinating center, perform meta-analysis using per-site approximations:
estimate <- computeBayesianMetaAnalysis(approximations)
plotPosterior(estimate)
```

---

plotPreparedPs

*Plot the propensity score distribution*

---

**Description**

Plot the propensity score distribution

**Usage**

```
plotPreparedPs(
  preparedPsPlots,
  labels,
  treatmentLabel = "Target",
  comparatorLabel = "Comparator",
  fileName = NULL
)
```

**Arguments**

preparedPsPlots	list of prepared propensity score data as created by the <code>preparePsPlot()</code> function.
labels	A vector containing the labels for the various sources.
treatmentLabel	A label to us for the treated cohort.
comparatorLabel	A label to us for the comparator cohort.
fileName	Name of the file where the plot should be saved, for example 'plot.png'. See the function <code>ggplot2::ggsave</code> for supported file formats.

**Value**

A ggplot object. Use the `ggplot2::ggsave` function to save to file in a different format.

**See Also**

[preparePsPlot](#)

**Examples**

```
# Simulate some data for this example:
treatment <- rep(0:1, each = 100)
propensityScore <- c(rnorm(100, mean = 0.4, sd = 0.25), rnorm(100, mean = 0.6, sd = 0.25))
data <- data.frame(treatment = treatment, propensityScore = propensityScore)
data <- data[data$propensityScore > 0 & data$propensityScore < 1, ]
preparedPlot <- preparePsPlot(data)

# Just reusing the same data three times for demonstration purposes:
preparedPsPlots <- list(preparedPlot, preparedPlot, preparedPlot)
labels <- c("Data site A", "Data site B", "Data site C")

plotPreparedPs(preparedPsPlots, labels)
```

---

```
preparePsPlot
```

*Prepare to plot the propensity score distribution*

---

**Description**

Prepare to plot the propensity (or preference) score distribution. It computes the distribution, so the output does not contain person-level data.

**Usage**

```
preparePsPlot(data, unfilteredData = NULL, scale = "preference")
```

## Arguments

data	A data frame with at least the two columns described below
unfilteredData	To be used when computing preference scores on data from which subjects have already been removed, e.g. through trimming and/or matching. This data frame should have the same structure as data.
scale	The scale of the graph. Two scales are supported: scale = 'propensity' or scale = 'preference'. The preference score scale is defined by Walker et al. (2013).

## Details

The data frame should have a least the following two columns:

- **treatment** (integer): Column indicating whether the person is in the treated (1) or comparator (0) group. - **propensityScore** (numeric): Propensity score.

## Value

A data frame describing the propensity score (or preference score) distribution at 100 equally-spaced points.

## References

Walker AM, Patrick AR, Lauer MS, Hornbrook MC, Marin MG, Platt R, Roger VL, Stang P, and Schneeweiss S. (2013) A tool for assessing the feasibility of comparative effectiveness research, *Comparative Effective Research*, 3, 11-20

## See Also

[plotPreparedPs](#)

## Examples

```
# Simulate some data for this example:
treatment <- rep(0:1, each = 100)
propensityScore <- c(rnorm(100, mean = 0.4, sd = 0.25), rnorm(100, mean = 0.6, sd = 0.25))
data <- data.frame(treatment = treatment, propensityScore = propensityScore)
data <- data[data$propensityScore > 0 & data$propensityScore < 1, ]

preparedPlot <- preparePsPlot(data)
```

---

`sequentialFitBiasDistribution`*Fit Bias Distribution Sequentially or in Groups*

---

**Description**

Learn empirical bias distributions sequentially or in groups; for each sequential step or analysis group, bias distributions is learned by by simultaneously analyzing a large set of negative control outcomes by a Bayesian hierarchical model through MCMC.

**Usage**

```
sequentialFitBiasDistribution(LikelihoodProfileList, ...)
```

**Arguments**

LikelihoodProfileList

A list of lists, each of which is a set of grid profile likelihoods regarding negative controls, indexed by analysis period ID for sequential analyses or group ID for group analyses.

... Arguments passed to the `fitBiasDistribution()` function.

**Value**

A (long) dataframe with four columns. Column mean includes MCMC samples for the average bias, scale for the sd/scale parameter, bias for predictive samples of the bias, and Id for the period ID or group ID.

**See Also**

[fitBiasDistribution](#), [computeBayesianMetaAnalysis](#)

**Examples**

```
# load example data
data("ncLikelihoods")

# fit bias distributions over analysis periods
# NOT RUN
# biasDistributions = sequentialFitBiasDistribution(ncLikelihoods, seed = 42)
```



---

simulatePopulations     *Simulate survival data for multiple databases*

---

**Description**

Simulate survival data for multiple databases

**Usage**

```
simulatePopulations(settings = createSimulationSettings())
```

**Arguments**

settings     An object of type simulationSettings, created by the `createSimulationSettings()` function.

**Value**

A object of class simulation, which is a list of populations, each a data frame with columns rowId, stratumId, x, time, and y.

**Examples**

```
settings <- createSimulationSettings(nSites = 1, hazardRatio = 2)
populations <- simulatePopulations(settings)

# Fit a Cox regression for the simulated data site:
cyclopsData <- Cyclops::createCyclopsData(Surv(time, y) ~ x + strata(stratumId),
  data = populations[[1]],
  modelType = "cox"
)
cyclopsFit <- Cyclops::fitCyclopsModel(cyclopsData)
coef(cyclopsFit)

# (Estimates in this example will vary due to the random simulation)
```

---

skewNormal     *The skew normal function to approximate a log likelihood function*

---

**Description**

The skew normal function to approximate a log likelihood function

**Usage**

```
skewNormal(x, mu, sigma, alpha)
```

**Arguments**

x	The log(hazard ratio) for which to approximate the log likelihood.
mu	The position parameter.
sigma	The scale parameter.
alpha	The skew parameter.

**Details**

The skew normal function. When  $\alpha = 0$  this function is the normal distribution.

**Value**

The approximate log likelihood for the given x.

**References**

Azzalini, A. (2013). The Skew-Normal and Related Families. Institute of Mathematical Statistics Monographs. Cambridge University Press.

**Examples**

```
skewNormal(x = 0:3, mu = 0, sigma = 1, alpha = 0)
```

---

supportsJava8

*Determine if Java virtual machine supports Java*

---

**Description**

Tests Java virtual machine (JVM) java.version system property to check if version  $\geq 8$ .

**Usage**

```
supportsJava8()
```

**Value**

Returns TRUE if JVM supports Java  $\geq 8$ .

**Examples**

```
supportsJava8()
```

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