Package 'BayesMallows'

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Type Package

Title Bayesian Preference Learning with the Mallows Rank Model

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Description An implementation of the Bayesian version of the Mallows rank model (Vitelli et al., Journal of Machine Learning Research, 2018 <http://jmlr.org/papers/v18/15-481.html>; Crispino et al., Annals of Applied Statistics, 2019 <doi:10.1214/18-AOAS1203>). Both Cayley, footrule, Hamming, Kendall, Spearman, and Ulam distances are supported in the models. The rank data to be analyzed can be in the form of complete rankings, top-k rankings, partially missing rankings, as well as consistent and inconsistent pairwise preferences. Several functions for plotting and studying the posterior distributions of parameters are provided. The package also provides functions for estimating the partition function (normalizing constant) of the Mallows rank model, both with the importance sampling algorithm of Vitelli et al. and asymptotic approximation with the IPFP algorithm (Mukherjee, Annals of Statistics, 2016 <doi:10.1214/15-AOS1389>).

URL https://github.com/ocbe-uio/BayesMallows

License GPL-3

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LazyData true

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Depends R (>= 2.10)

Imports Rcpp (>= 1.0.0), ggplot2 (>= 3.1.0), Rdpack (>= 0.8), stats, igraph (>= 1.2.2), dplyr (>= 1.0.1), sets (>= 1.0-18), relations (>= 0.6-8), tidyr (>= 1.1.1), purrr (>= 0.3.0), rlang (>= 0.3.1), PerMallows (>= 1.13), HDInterval (>= 0.2.0), cowplot (>= 0.9.3)

LinkingTo Rcpp, RcppArmadillo

Suggests R.rsp, testthat (>= 2.0), label.switching (>= 1.7), readr (>= 1.3.1), stringr (>= 1.4.0), gtools (>= 3.8.1), rmarkdown, covr, parallel (>= 3.5.1)

VignetteBuilder R.rsp

RdMacros Rdpack

NeedsCompilation yes

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R topics documented:

assess_convergence *Trace Plots from Metropolis-Hastings Algorithm*

Description

assess_convergence provides trace plots for the parameters of the Mallows Rank model, in order to study the convergence of the Metropolis-Hastings algorithm.

Usage

```
assess_convergence(
  model_fit,
  parameter = "alpha",
  items = NULL,
  assessors = NULL
)
```

Arguments

model_fit	A fitted model object of class BayesMallows returned from compute_mallows or an object of class BayesMallowsMixtures returned from compute_mallows_mixtures.
parameter	Character string specifying which parameter to plot. Available options are "alpha", "rho", "Rtilde", "cluster_probs", or "theta".
items	The items to study in the diagnostic plot for rho. Either a vector of item names, corresponding to model_fit$items or a vector of indices. If NULL, five items are selected randomly. Only used when parameter = "rho" or parameter = "Rtilde".
assessors	Numeric vector specifying the assessors to study in the diagnostic plot for "Rtilde".

See Also

compute_mallows, plot.BayesMallows

assign_cluster *Assign Assessors to Clusters*

Description

Assign assessors to clusters by finding the cluster with highest posterior probability.

Usage

```
assign_cluster(
  model_fit,
  burnin = model_fit$burnin,
  soft = TRUE,
  expand = FALSE
)
```

Arguments

model_fit	An object of type BayesMallows, returned from compute_mallows.
burnin	A numeric value specifying the number of iterations to discard as burn-in. Defaults to model_fit$burnin, and must be provided if model_fit$burnin does not exist. See assess_convergence.
soft	A logical specifying whether to perform soft or hard clustering. If soft=TRUE, all cluster probabilities are returned, whereas if soft=FALSE, only the maximum a posterior (MAP) cluster probability is returned, per assessor. In the case of a tie between two or more cluster assignments, a random cluster is taken as MAP estimate.
expand	A logical specifying whether or not to expand the rowset of each assessor to also include clusters for which the assessor has 0 a posterior assignment probability. Only used when soft = TRUE. Defaults to FALSE.

Value

A dataframe. If soft = FALSE, it has one row per assessor, and columns assessor, probability and map_cluster. If soft = TRUE, it has n_cluster rows per assessor, and the additional column cluster.

See Also

compute_mallows for an example where this function is used.

BayesMallows *BayesMallows: Bayesian Preference Learning with the Mallows Rank Model.*

Description

The BayesMallows package provides functionality for fully Bayesian analysis of preference or rank data. The package implements the Bayesian Mallows model described in Vitelli et al. (2018), which handles complete rankings, top-k rankings, ranks missing at random, and consistent pairwise preference data, as well as mixtures of rank models. Modeling of pairwise preferences containing inconsistencies, as described in Crispino et al. (2019), is also supported.

The documentation and examples for the following functions are likely most useful to get you started:

- For analysis of rank or preference data, see compute_mallows.
- For computation of multiple models with varying numbers of mixture components, see compute_mallows_mixtures.
- For estimation of the partition function (normalizing constant) using either the importance sampling algorithm of Vitelli et al. (2018) or the asymptotic algorithm of Mukherjee (2016), see estimate_partition_function.

References

Crispino M, Arjas E, Vitelli V, Barrett N, Frigessi A (2019). "A Bayesian Mallows approach to nontransitive pair comparison data: How human are sounds?" *The Annals of Applied Statistics*, **13**(1), 492–519. doi: 10.1214/18aoas1203, https://doi.org/10.1214/18-aoas1203.

Mukherjee S (2016). "Estimation in exponential families on permutations." *The Annals of Statistics*, **44**(2), 853–875. doi: 10.1214/15aos1389, https://doi.org/10.1214/15-aos1389.

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

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beach_preferences *Beach Preferences*

Description

Example dataset from (Vitelli et al. 2018), Section 6.2.

Usage

```
beach_preferences
```

Format

An object of class tbl_df (inherits from tbl, data.frame) with 1442 rows and 3 columns.

References

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

compute_consensus *Compute Consensus Ranking*

Description

Compute the consensus ranking using either cumulative probability (CP) or maximum a posteriori (MAP) consensus (Vitelli et al. 2018). For mixture models, the consensus is given for each mixture.

Usage

```
compute_consensus(model_fit, type = "CP", burnin = model_fit$burnin)
```

Arguments

model_fit	An object returned from compute_mallows.
type	Character string specifying which consensus to compute. Either "CP" or "MAP". Defaults to "CP".
burnin	A numeric value specifying the number of iterations to discard as burn-in. Defaults to model_fit$burnin, and must be provided if model_fit$burnin does not exist. See assess_convergence.

References

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

Examples

```
# The example datasets potato_visual and potato_weighing contain complete
# rankings of 20 items, by 12 assessors. We first analyse these using the Mallows
# model:
model_fit <- compute_mallows(potato_visual)

# Se the documentation to compute_mallows for how to assess the convergence of the algorithm
# Having chosen burin = 1000, we compute posterior intervals
model_fit$burnin <- 1000
# We then compute the CP consensus.
compute_consensus(model_fit, type = "CP")
# And we compute the MAP consensus
compute_consensus(model_fit, type = "MAP")

## Not run:
  # CLUSTERWISE CONSENSUS
  # We can run a mixture of Mallows models, using the n_clusters argument
 # We use the sushi example data. See the documentation of compute_mallows for a more elaborate
  # example
  model_fit <- compute_mallows(sushi_rankings, n_clusters = 5)
```

```
  # Keeping the burnin at 1000, we can compute the consensus ranking per cluster
  model_fit$burnin <- 1000
  cp_consensus_df <- compute_consensus(model_fit, type = "CP")
  # Using dplyr::select and tidyr::cumprob we can now make a table
  # which shows the ranking in each cluster:
  library(dplyr)
  library(tidyr)
  cp_consensus_df %>%
    select(-cumprob) %>%
    spread(key = cluster, value = item)

## End(Not run)

## Not run:
  # MAP CONSENSUS FOR PAIRWISE PREFENCE DATA
  # We use the example dataset with beach preferences.
  model_fit <- compute_mallows(preferences = beach_preferences)
  # We set burnin = 1000
  model_fit$burnin <- 1000
  # We now compute the MAP consensus
  map_consensus_df <- compute_consensus(model_fit, type = "MAP")

## End(Not run)
```

`compute_mallows` *Preference Learning with the Mallows Rank Model*

Description

Compute the posterior distributions of the parameters of the Bayesian Mallows Rank Model, given rankings or preferences stated by a set of assessors.

The `BayesMallows` package uses the following parametrization of the Mallows rank model (Mallows 1957):

$$p(r|\alpha, \rho) = (1/Z_n(\alpha)) \exp -\alpha/n d(r, \rho)$$

where r is a ranking, α is a scale parameter, ρ is the latent consensus ranking, $Z_n(\alpha)$ is the partition function (normalizing constant), and $d(r, \rho)$ is a distance function measuring the distance between r and ρ. Note that some authors use a Mallows model without division by n in the exponent; this includes the `PerMallows` package, whose scale parameter θ corresponds to α/n in the `BayesMallows` package. We refer to (Vitelli et al. 2018) for further details of the Bayesian Mallows model.

`compute_mallows` always returns posterior distributions of the latent consensus ranking ρ and the scale parameter α. Several distance measures are supported, and the preferences can take the form of complete or incomplete rankings, as well as pairwise preferences. `compute_mallows` can also compute mixtures of Mallows models, for clustering of assessors with similar preferences.

Usage

```
compute_mallows(
  rankings = NULL,
```

```
  preferences = NULL,
  metric = "footrule",
  error_model = NULL,
  n_clusters = 1L,
  save_clus = FALSE,
  clus_thin = 1L,
  nmc = 2000L,
  leap_size = max(1L, floor(n_items/5)),
  swap_leap = 1L,
  rho_init = NULL,
  rho_thinning = 1L,
  alpha_prop_sd = 0.1,
  alpha_init = 1,
  alpha_jump = 1L,
  lambda = 0.001,
  alpha_max = 1e+06,
  psi = 10L,
  include_wcd = (n_clusters > 1),
  save_aug = FALSE,
  aug_thinning = 1L,
  logz_estimate = NULL,
  verbose = FALSE,
  validate_rankings = TRUE,
  constraints = NULL,
  save_ind_clus = FALSE,
  seed = NULL
)
```

Arguments

rankings	A matrix of ranked items, of size n_assessors x n_items. See create_ranking if you have an ordered set of items that need to be converted to rankings. If preferences is provided, rankings is an optional initial value of the rankings, generated by generate_initial_ranking. If rankings has column names, these are assumed to be the names of the items.
preferences	A dataframe with pairwise comparisons, with 3 columns, named assessor, bottom_item, and top_item, and one row for each stated preference. Given a set of pairwise preferences, generate a transitive closure using generate_transitive_closure. This will give preferences the class "BayesMallowsTC". If preferences is not of class "BayesMallowsTC", compute_mallows will call generate_transitive_closure on preferences before computations are done. In the current version, the pairwise preferences are assumed to be mutually compatible.
metric	A character string specifying the distance metric to use in the Bayesian Mallows Model. Available options are "footrule", "spearman", "cayley", "hamming", "kendall", and "ulam". The distance given by metric is also used to compute within-cluster distances, when include_wcd = TRUE.
error_model	Character string specifying which model to use for inconsistent rankings. Defaults to NULL, which means that inconsistent rankings are not allowed. At the

moment, the only available other option is "bernoulli", which means that the Bernoulli error model is used. See Crispino et al. (2019) for a definition of the Bernoulli model.

n_clusters — Integer specifying the number of clusters, i.e., the number of mixture components to use. Defaults to 1L, which means no clustering is performed. See compute_mallows_mixtures for a convenience function for computing several models with varying numbers of mixtures.

save_clus — Logical specifying whether or not to save cluster assignments. Defaults to FALSE.

clus_thin — Integer specifying the thinning to be applied to cluster assignments and cluster probabilities. Defaults to 1L.

nmc — Integer specifying the number of iteration of the Metropolis-Hastings algorithm to run. Defaults to 2000L. See assess_convergence for tools to check convergence of the Markov chain.

leap_size — Integer specifying the step size of the leap-and-shift proposal distribution. Defaults floor(n_items / 5).

swap_leap — Integer specifying the step size of the Swap proposal. Only used when error_model is not NULL.

rho_init — Numeric vector specifying the initial value of the latent consensus ranking ρ. Defaults to NULL, which means that the initial value is set randomly. If rho_init is provided when n_clusters > 1, each mixture component ρ_c gets the same initial value.

rho_thinning — Integer specifying the thinning of rho to be performed in the Metropolis- Hastings algorithm. Defaults to 1L. compute_mallows save every rho_thinningth value of ρ.

alpha_prop_sd — Numeric value specifying the standard deviation of the lognormal proposal distribution used for α in the Metropolis-Hastings algorithm. Defaults to 0.1.

alpha_init — Numeric value specifying the initial value of the scale parameter α. Defaults to 1. When n_clusters > 1, each mixture component α_c gets the same initial value.

alpha_jump — Integer specifying how many times to sample ρ between each sampling of α. In other words, how many times to jump over α while sampling ρ, and possibly other parameters like augmented ranks $\tilde{R}$ or cluster assignments z. Setting alpha_jump to a high number can speed up computation time, by reducing the number of times the partition function for the Mallows model needs to be computed. Defaults to 1L.

lambda — Strictly positive numeric value specifying the rate parameter of the truncated exponential prior distribution of α. Defaults to 0.1. When n_cluster > 1, each mixture component α_c has the same prior distribution.

alpha_max — Maximum value of alpha in the truncated exponential prior distribution.

psi — Integer specifying the concentration parameter ψ of the Dirichlet prior distribution used for the cluster probabilities $\tau_1, \tau_2, \ldots, \tau_C$, where C is the value of n_clusters. Defaults to 10L. When n_clusters = 1, this argument is not used.

include_wcd — Logical indicating whether to store the within-cluster distances computed during the Metropolis-Hastings algorithm. Defaults to TRUE if n_clusters > 1 and otherwise FALSE. Setting include_wcd = TRUE is useful when deciding the number of mixture components to include, and is required by plot_elbow.

save_aug — Logical specifying whether or not to save the augmented rankings every aug_thinningth iteration, for the case of missing data or pairwise preferences. Defaults to FALSE. Saving augmented data is useful for predicting the rankings each assessor would give to the items not yet ranked, and is required by plot_top_k.

aug_thinning — Integer specifying the thinning for saving augmented data. Only used when save_aug = TRUE. Defaults to 1L.

logz_estimate — Estimate of the partition function, computed with estimate_partition_function. Be aware that when using an estimated partition function when n_clusters > 1, the partition function should be estimated over the whole range of α values covered by the prior distribution for α with high probability. In the case that a cluster α_c becomes empty during the Metropolis-Hastings algorihm, the posterior of α_c equals its prior. For example, if the rate parameter of the exponential prior equals, say $\lambda = 0.001$, there is about 37 % (or exactly: 1 -pexp(1000,0.001)) prior probability that $\alpha_c > 1000$. Hence when n_clusters > 1, the estimated partition function should cover this range, or λ should be increased.

verbose — Logical specifying whether to print out the progress of the Metropolis-Hastings algorithm. If TRUE, a notification is printed every 1000th iteration. Defaults to FALSE.

validate_rankings — Logical specifying whether the rankings provided (or generated from preferences) should be validated. Defaults to TRUE. Turning off this check will reduce computing time with a large number of items or assessors.

constraints — Optional constraint set returned from generate_constraints. Defaults to NULL, which means the the constraint set is computed internally. In repeated calls to compute_mallows, with very large datasets, computing the constraint set may be time consuming. In this case it can be beneficial to precompute it and provide it as a separate argument.

save_ind_clus — Whether or not to save the individual cluster probabilities in each step. This results in csv files cluster_probs1.csv, cluster_probs2.csv, ..., being saved in the calling directory. This option may slow down the code considerably, but is necessary for detecting label switching using Stephen's algorithm. See label_switching for more information.

seed — Optional integer to be used as random number seed.

Value

A list of class BayesMallows.

References

Crispino M, Arjas E, Vitelli V, Barrett N, Frigessi A (2019). "A Bayesian Mallows approach to nontransitive pair comparison data: How human are sounds?" *The Annals of Applied Statistics*, **13**(1), 492–519. doi: 10.1214/18aoas1203, https://doi.org/10.1214/18-aoas1203.

Mallows CL (1957). "Non-Null Ranking Models. I." *Biometrika*, **44**(1/2), 114–130.

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

See Also

compute_mallows_mixtures for a function that computes separate Mallows models for varying numbers of clusters.

Examples

```
# ANALYSIS OF COMPLETE RANKINGS
# The example datasets potato_visual and potato_weighing contain complete
# rankings of 20 items, by 12 assessors. We first analyse these using the Mallows
# model:
model_fit <- compute_mallows(potato_visual)

# We study the trace plot of the parameters
assess_convergence(model_fit, parameter = "alpha")
## Not run: assess_convergence(model_fit, parameter = "rho")

# Based on these plots, we set burnin = 1000.
model_fit$burnin <- 1000
# Next, we use the generic plot function to study the posterior distributions
# of alpha and rho
plot(model_fit, parameter = "alpha")
## Not run: plot(model_fit, parameter = "rho", items = 10:15)

# We can also compute the CP consensus posterior ranking
compute_consensus(model_fit, type = "CP")

# And we can compute the posterior intervals:
# First we compute the interval for alpha
compute_posterior_intervals(model_fit, parameter = "alpha")
# Then we compute the interval for all the items
## Not run: compute_posterior_intervals(model_fit, parameter = "rho")

# ANALYSIS OF PAIRWISE PREFERENCES
## Not run:
  # The example dataset beach_preferences contains pairwise
  # preferences between beaches stated by 60 assessors. There
  # is a total of 15 beaches in the dataset.
  # In order to use it, we first generate all the orderings
  # implied by the pairwise preferences.
  beach_tc <- generate_transitive_closure(beach_preferences)
  # We also generate an inital rankings
  beach_rankings <- generate_initial_ranking(beach_tc, n_items = 15)
  # We then run the Bayesian Mallows rank model
  # We save the augmented data for diagnostics purposes.
```

```
  model_fit <- compute_mallows(rankings = beach_rankings,
                               preferences = beach_tc,
                               save_aug = TRUE,
                               verbose = TRUE)
  # We can assess the convergence of the scale parameter
  assess_convergence(model_fit)
  # We can assess the convergence of latent rankings. Here we
  # show beaches 1-5.
  assess_convergence(model_fit, parameter = "rho", items = 1:5)
  # We can also look at the convergence of the augmented rankings for
  # each assessor.
  assess_convergence(model_fit, parameter = "Rtilde",
                     items = c(2, 4), assessors = c(1, 2))
  # Notice how, for assessor 1, the lines cross each other, while
  # beach 2 consistently has a higher rank value (lower preference) for
  # assessor 2. We can see why by looking at the implied orderings in
  # beach_tc
  library(dplyr)
  beach_tc %>%
    filter(assessor %in% c(1, 2),
           bottom_item %in% c(2, 4) & top_item %in% c(2, 4))
  # Assessor 1 has no implied ordering between beach 2 and beach 4,
  # while assessor 2 has the implied ordering that beach 4 is preferred
  # to beach 2. This is reflected in the trace plots.

## End(Not run)

# CLUSTERING OF ASSESSORS WITH SIMILAR PREFERENCES
## Not run:
  # The example dataset sushi_rankings contains 5000 complete
  # rankings of 10 types of sushi
  # We start with computing a 3-cluster solution, and save
  # cluster assignments by setting save_clus = TRUE
  model_fit <- compute_mallows(sushi_rankings, n_clusters = 3,
                               nmc = 10000, save_clus = TRUE, verbose = TRUE)
  # We then assess convergence of the scale parameter alpha
  assess_convergence(model_fit)
  # Next, we assess convergence of the cluster probabilities
  assess_convergence(model_fit, parameter = "cluster_probs")
  # Based on this, we set burnin = 1000
  # We now plot the posterior density of the scale parameters alpha in
  # each mixture:
  model_fit$burnin <- 1000
  plot(model_fit, parameter = "alpha")
  # We can also compute the posterior density of the cluster probabilities
  plot(model_fit, parameter = "cluster_probs")
  # We can also plot the posterior cluster assignment. In this case,
  # the assessors are sorted according to their maximum a posteriori cluster estimate.
  plot(model_fit, parameter = "cluster_assignment")
  # We can also assign each assessor to a cluster
  cluster_assignments <- assign_cluster(model_fit, soft = FALSE)

## End(Not run)
```

```
# DETERMINING THE NUMBER OF CLUSTERS
## Not run:
  # Continuing with the sushi data, we can determine the number of cluster
  # Let us look at any number of clusters from 1 to 10
  # We use the convenience function compute_mallows_mixtures
  n_clusters <- seq(from = 1, to = 10)
  models <- compute_mallows_mixtures(n_clusters = n_clusters, rankings = sushi_rankings,
                                     nmc = 6000, alpha_jump = 10, include_wcd = TRUE)
  # models is a list in which each element is an object of class BayesMallows,
  # returned from compute_mallows
  # We can create an elbow plot
  plot_elbow(models, burnin = 1000)
  # We then select the number of cluster at a point where this plot has
  # an "elbow", e.g., at 6 clusters.

## End(Not run)
```

`compute_mallows_mixtures` *Compute Mixtures of Mallows Models*

Description

Convenience function for computing Mallows models with varying numbers of mixtures. This is useful for deciding the number of mixtures to use in the final model.

Usage

```
compute_mallows_mixtures(n_clusters, ..., cl = NULL)
```

Arguments

`n_clusters`	Integer vector specifying the number of clusters to use.
`...`	Other named arguments, passed to `compute_mallows`.
`cl`	Optional computing cluster used for parallelization, returned from `parallel::makeCluster`. Defaults to `NULL`.

Value

A list of Mallows models of class `BayesMallowsMixtures`, with one element for each number of mixtures that was computed. This object can be studied with `plot_elbow`.

Examples

```
# DETERMINING THE NUMBER OF CLUSTERS IN THE SUSHI EXAMPLE DATA
## Not run:
  # Let us look at any number of clusters from 1 to 10
  # We use the convenience function compute_mallows_mixtures
  n_clusters <- seq(from = 1, to = 10)
  models <- compute_mallows_mixtures(n_clusters = n_clusters,
                                     rankings = sushi_rankings,
                                     include_wcd = TRUE)
  # models is a list in which each element is an object of class BayesMallows,
  # returned from compute_mallows
  # We can create an elbow plot
  plot_elbow(models, burnin = 1000)
  # We then select the number of cluster at a point where this plot has
  # an "elbow", e.g., n_clusters = 5.

  # Having chosen the number of clusters, we can now study the final model
  # Rerun with 5 clusters, now setting save_clus = TRUE to get cluster assignments
  mixture_model <- compute_mallows(rankings = sushi_rankings, n_clusters = 5,
                                   include_wcd = TRUE, save_clus = TRUE)
  # Delete the models object to free some memory
  rm(models)
  # Set the burnin
  mixture_model$burnin <- 1000
  # Plot the posterior distributions of alpha per cluster
  plot(mixture_model)
  # Compute the posterior interval of alpha per cluster
  compute_posterior_intervals(mixture_model,
                              parameter = "alpha")
  # Plot the posterior distributions of cluster probabilities
  plot(mixture_model, parameter = "cluster_probs")
  # Plot the posterior probability of cluster assignment
  plot(mixture_model, parameter = "cluster_assignment")
  # Plot the posterior distribution of "tuna roll" in each cluster
  plot(mixture_model, parameter = "rho", items = "tuna roll")
  # Compute the cluster-wise CP consensus, and show one column per cluster
  cp <- compute_consensus(mixture_model, type = "CP")
  library(dplyr)
  library(tidyr)
  cp %>%
    select(-cumprob) %>%
    spread(key = cluster, value = item)
  # Compute the MAP consensus, and show one column per cluster
  map <- compute_consensus(mixture_model, type = "MAP")
  map %>%
    select(-probability) %>%
    spread(key = cluster, value = item)

  # RUNNING IN PARALLEL
  # Computing Mallows models with different number of mixtures in parallel leads to
  # considerably speedup
  library(parallel)
```

```
  cl <- makeCluster(detectCores() - 1)
  n_clusters <- seq(from = 1, to = 10)
  models <- compute_mallows_mixtures(n_clusters = n_clusters,
                                     rankings = sushi_rankings,
                                     include_wcd = TRUE, cl = cl)
  stopCluster(cl)

## End(Not run)
```

`compute_posterior_intervals` *Compute Posterior Intervals*

Description

Compute posterior intervals of parameters of interest.

Usage

```
compute_posterior_intervals(
  model_fit,
  burnin = model_fit$burnin,
  parameter = "alpha",
  level = 0.95,
  decimals = 3L
)
```

Arguments

`model_fit`	An object returned from `compute_mallows`.
`burnin`	A numeric value specifying the number of iterations to discard as burn-in. Defaults to `model_fit$burnin`, and must be provided if `model_fit$burnin` does not exist. See `assess_convergence`.
`parameter`	Character string defining which parameter to compute posterior intervals for. One of `"alpha"`, `"rho"`, or `"cluster_probs"`. Default is `"alpha"`.
`level`	Decimal number in $[0, 1]$ specifying the confidence level. Defaults to `0.95`.
`decimals`	Integer specifying the number of decimals to include in posterior intervals and the mean and median. Defaults to `3`.

Details

This function computes both the Highest Posterior Density Interval (HPDI), which may be discontinuous for bimodal distributions, and the central posterior interval, which is simply defined by the quantiles of the posterior distribution. The HPDI intervals are computed using the `HDInterval` package (Meredith and Kruschke 2018).

References

Meredith M, Kruschke J (2018). *HDInterval: Highest (Posterior) Density Intervals*. R package version 0.2.0, https://CRAN.R-project.org/package=HDInterval.

See Also

compute_mallows

Examples

```
# The example datasets potato_visual and potato_weighing contain complete
# rankings of 20 items, by 12 assessors. We first analyse these using the Mallows
# model:
model_fit <- compute_mallows(potato_visual)

# Se the documentation to compute_mallows for how to assess the convergence of the algorithm
# Having chosen burin = 1000, we compute posterior intervals
model_fit$burnin <- 1000
# First we compute the interval for alpha
compute_posterior_intervals(model_fit, parameter = "alpha")
# We can reduce the number decimals
compute_posterior_intervals(model_fit, parameter = "alpha", decimals = 2)
# By default, we get a 95 % interval. We can change that to 99 %.
compute_posterior_intervals(model_fit, parameter = "alpha", level = 0.99)
# We can also compute the posterior interval for the latent ranks rho
compute_posterior_intervals(model_fit, parameter = "rho")

## Not run:
  # Posterior intervals of cluster probabilities
  # We can run a mixture of Mallows models, using the n_clusters argument
 # We use the sushi example data. See the documentation of compute_mallows for a more elaborate
  # example
  model_fit <- compute_mallows(sushi_rankings, n_clusters = 5)
 # Keeping the burnin at 1000, we can compute the posterior intervals of the cluster probabilities
  compute_posterior_intervals(model_fit, burnin = 1000, parameter = "cluster_probs")

## End(Not run)
```

---

estimate_partition_function

Estimate Partition Function

Description

Estimate the logarithm of the partition function of the Mallows rank model. Choose between the importance sampling algorithm described in (Vitelli et al. 2018) and the IPFP algorithm for computing an asymptotic approximation described in (Mukherjee 2016).

Usage

```
estimate_partition_function(
  method = "importance_sampling",
  alpha_vector,
  n_items,
  metric,
  nmc,
  degree,
  n_iterations,
  K,
  cl = NULL
)
```

Arguments

method	Character string specifying the method to use in order to estimate the logarithm of the partition function. Available options are "importance_sampling" and "asymptotic".
alpha_vector	Numeric vector of α values over which to compute the importance sampling estimate.
n_items	Integer specifying the number of items.
metric	Character string specifying the distance measure to use. Available options are "footrule" and "spearman"
nmc	Integer specifying the number of Monte Carlo samples to use in the importance sampling. Only used when method = "importance_sampling".
degree	Integer specifying the degree of the polynomial used to estimate $\log(\alpha)$ from the grid of values provided by the importance sampling estimate.
n_iterations	Integer specifying the number of iterations to use in the asymptotic approximation of the partition function. Only used when method = "asymptotic".
K	Integer specifying the parameter K in the asymptotic approximation of the partition function. Only used when method = "asymptotic".
cl	Optional computing cluster used for parallelization, returned from parallel::makeCluster. Defaults to NULL. Only used when method = "importance_sampling".

Value

A vector of length degree which can be supplied to the logz_estimate argument of compute_mallows.

References

Mukherjee S (2016). "Estimation in exponential families on permutations." *The Annals of Statistics*, **44**(2), 853–875. doi: 10.1214/15aos1389, https://doi.org/10.1214/15-aos1389.

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

Examples

```
## Not run:
  # IMPORTANCE SAMPLING
  # Let us estimate logZ(alpha) for 20 items with Spearman distance
  # We create a grid of alpha values from 0 to 10
  alpha_vector <- seq(from = 0, to = 10, by = 0.5)
  n_items <- 20
  metric <- "spearman"
  degree <- 10

  # We start with 1e3 Monte Carlo samples
  fit1 <- estimate_partition_function(method = "importance_sampling",
                                      alpha_vector = alpha_vector,
                                      n_items = n_items, metric = metric,
                                      nmc = 1e3, degree = degree)
  # A vector of polynomial regression coefficients is returned
  fit1

  # Now let us recompute with 1e4 Monte Carlo samples
  fit2 <- estimate_partition_function(method = "importance_sampling",
                                      alpha_vector = alpha_vector,
                                      n_items = n_items, metric = metric,
                                      nmc = 1e4, degree = degree)

  # ASYMPTOTIC APPROXIMATION
  # We can also compute an estimate using the asymptotic approximation
  K <- 20
  n_iterations <- 50

  fit3 <- estimate_partition_function(method = "asymptotic",
                                      alpha_vector = alpha_vector,
                                      n_items = n_items, metric = metric,
                                      n_iterations = n_iterations,
                                      K = K, degree = degree)

  # We write a little function for storing the estimates in a dataframe
  library(dplyr)
  powers <- seq(from = 0, to = degree, by = 1)

  compute_fit <- function(fit){
    tibble(alpha = alpha_vector) %>%
      rowwise() %>%
      mutate(logz_estimate = sum(alpha^powers * fit))
  }

  estimates <- bind_rows(
    "Importance Sampling 1e3" = compute_fit(fit1),
    "Importance Sampling 1e4" = compute_fit(fit2),
    "Asymptotic" = compute_fit(fit3),
    .id = "type")

  # We can now plot the two estimates side-by-side
```

```
library(ggplot2)
ggplot(estimates, aes(x = alpha, y = logz_estimate, color = type)) +
  geom_line()
# We see that the two importance sampling estimates, which are unbiased,
# overlap. The asymptotic approximation seems a bit off. It can be worthwhile
# to try different values of n_iterations and K.

# When we are happy, we can provide the coefficient vector in the
# logz_estimate argument to compute_mallows
# Say we choose to use the importance sampling estimate with 1e4 Monte Carlo samples:
model_fit <- compute_mallows(potato_visual, metric = "spearman",
                             logz_estimate = fit2)


## End(Not run)
```

`generate_constraints` *Generate Constraint Set from Pairwise Comparisons*

Description

This function is relevant when `compute_mallows` is called repeatedly with the same data, e.g., when determining the number of clusters. It precomputes a list of constraints used internally by the MCMC algorithm, which otherwise would be recomputed each time `compute_mallows` is called.

Usage

```
generate_constraints(preferences, n_items, cl = NULL)
```

Arguments

`preferences`	Data frame of preferences. For the case of consistent rankings, `preferences` should be returned from `generate_transitive_closure`. For the case of inconsistent preferences, when using an error model as described in Crispino et al. (2019), a dataframe of preferences can be directly provided.
`n_items`	Integer specifying the number of items.
`cl`	Optional computing cluster used for parallelization, returned from `parallel::makeCluster`. Defaults to `NULL`.

Value

A list which is used internally by the MCMC algorithm.

References

Crispino M, Arjas E, Vitelli V, Barrett N, Frigessi A (2019). "A Bayesian Mallows approach to nontransitive pair comparison data: How human are sounds?" *The Annals of Applied Statistics*, **13**(1), 492–519. doi: 10.1214/18aoas1203, https://doi.org/10.1214/18-aoas1203.

Examples

```
# Here is an example with the beach preference data.
# First, generate the transitive closure.
beach_tc <- generate_transitive_closure(beach_preferences)

# Next, generate an initial ranking.
beach_init_rank <- generate_initial_ranking(beach_tc)

# Then generate the constrain set used intervally by compute_mallows
constr <- generate_constraints(beach_tc, n_items = 15)

# Provide all these elements to compute_mallows
model_fit <- compute_mallows(rankings = beach_init_rank,
preferences = beach_tc, constraints = constr)

## Not run:
  # The constraints can also be generated in parallel
  library(parallel)
  cl <- makeCluster(detectCores() - 1)
  constr <- generate_constraints(beach_tc, n_items = 15, cl = cl)
  stopCluster(cl)

## End(Not run)
```

---

generate_initial_ranking

Generate Initial Ranking

Description

Given a consistent set of pairwise preferences, generate a complete ranking of items which is consistent with the preferences.

Usage

```
generate_initial_ranking(
  tc,
  n_items = max(tc[, c("bottom_item", "top_item")]),
  cl = NULL
)
```

Arguments

tc	A dataframe with pairwise comparisons of S3 subclass BayesMallowsTC, returned from generate_transitive_closure.
n_items	The total number of items. If not provided, it is assumed to equal the largest item index found in tc, i.e., max(tc[,c("bottom_item","top_item")]).
cl	Optional computing cluster used for parallelization, returned from parallel::makeCluster. Defaults to NULL.

Value

A matrix of rankings which can be given in the rankings argument to compute_mallows.

Examples

```
# The example dataset beach_preferences contains pairwise prefences of beach.
# We must first generate the transitive closure
beach_tc <- generate_transitive_closure(beach_preferences)

# Next, we generate an initial ranking
beach_init <- generate_initial_ranking(beach_tc)

# Look at the first few rows:
head(beach_init)

# We can add more informative column names in order
# to get nicer posterior plots:
colnames(beach_init) <- paste("Beach", seq(from = 1, to = ncol(beach_init), by = 1))
head(beach_init)

## Not run:
  # We now give beach_init and beach_tc to compute_mallows. We tell compute_mallows
  # to save the augmented data, in order to study the convergence.
  model_fit <- compute_mallows(rankings = beach_init,
                               preferences = beach_tc,
                               nmc = 2000,
                               save_aug = TRUE)

  # We can study the acceptance rate of the augmented rankings
  assess_convergence(model_fit, parameter = "Rtilde")

  # We can also study the posterior distribution of the consensus rank of each beach
  model_fit$burnin <- 500
  plot(model_fit, parameter = "rho", items = 1:15)

## End(Not run)

## Not run:
  # The computations can also be done in parallel
  library(parallel)
  cl <- makeCluster(detectCores() - 1)
  beach_tc <- generate_transitive_closure(beach_preferences, cl = cl)
  beach_init <- generate_initial_ranking(beach_tc, cl = cl)
  stopCluster(cl)

## End(Not run)
```

---

generate_transitive_closure

Generate Transitive Closure

Description

Generate the transitive closure for a set of consistent pairwise comparisons. The result can be given in the `preferences` argument to `compute_mallows`.

Usage

```
generate_transitive_closure(df, cl = NULL)
```

Arguments

`df` A data frame with one row per pairwise comparison, and columns `assessor`, `top_item`, and `bottom_item`. Each column contains the following:

- `assessor` is a numeric vector containing the assessor index, or a character vector containing the (unique) name of the assessor.
- `bottom_item` is a numeric vector containing the index of the item that was disfavored in each pairwise comparison.
- `top_item` is a numeric vector containing the index of the item that was preferred in each pairwise comparison.

So if we have two assessors and five items, and assessor 1 prefers item 1 to item 2 and item 1 to item 5, while assessor 2 prefers item 3 to item 5, we have the following `df`:

assessor	bottom_item	top_item
1	2	1
1	5	1
2	5	3

`cl` Optional computing cluster used for parallelization, returned from `parallel::makeCluster`. Defaults to `NULL`.

Value

A dataframe with the same columns as `df`, but with its set of rows expanded to include all pairwise preferences implied by the ones stated in `df`. The returned object has `S3` subclass `BayesMallowsTC`, to indicate that this is the transitive closure.

See Also

`generate_initial_ranking`

Examples

```
# Let us first consider a simple case with two assessors, where assessor 1
# prefers item 1 to item 2, and item 1 to item 5, while assessor 2 prefers
# item 3 to item 5. We then have the following dataframe of pairwise
# comparisons:
library(dplyr)
```

```
pair_comp <- tribble(
  ~assessor, ~bottom_item, ~top_item,
  1, 2, 1,
  1, 5, 1,
  2, 5, 3
)
# We then generate the transitive closure of these preferences:
(pair_comp_tc <- generate_transitive_closure(pair_comp))
# In this case, no additional relations we implied by the ones
# stated in pair_comp, so pair_comp_tc has exactly the same rows
# as pair_comp.

# Now assume that assessor 1 also preferred item 5 to item 3, and
# that assessor 2 preferred item 4 to item 3.
pair_comp <- tribble(
  ~assessor, ~bottom_item, ~top_item,
  1, 2, 1,
  1, 5, 1,
  1, 3, 5,
  2, 5, 3,
  2, 3, 4
)
# We generate the transitive closure again:
(pair_comp_tc <- generate_transitive_closure(pair_comp))
# We now have one implied relation for each assessor.
# For assessor 1, it is implied that 1 is preferred to 3.
# For assessor 2, it is implied that 4 is preferred to 5.

## Not run:
  # If assessor 1 in addition preferred item 3 to item 1,
  # the preferences would not be consistent. This is not yet supported by compute_mallows,
  # so it causes an error message. It will be supported in a future release of the package.
  # First, we add the inconsistent row to pair_comp
  pair_comp <- bind_rows(pair_comp,
                         tibble(assessor = 1, bottom_item = 1, top_item = 3))

  # This causes an error message and prints out the problematic rankings:
  (pair_comp_tc <- generate_transitive_closure(pair_comp))

## End(Not run)


## Not run:
  # The computations can also be done in parallel
  library(parallel)
  cl <- makeCluster(detectCores() - 1)
  beach_tc <- generate_transitive_closure(beach_preferences, cl = cl)
  stopCluster(cl)

## End(Not run)
```

label_switching *Checking for Label Switching in the Mallows Mixture Model*

Description

Label switching may sometimes be a problem when running mixture models. The algorithm by Stephens (Stephens 2000), implemented in the `label.switching` package (Papastamoulis 2016), allows assessment of label switching after MCMC. At the moment, this is the only avaiable option in the `BayesMallows` package. The Stephens algorithms requires the individual cluster probabilities of each assessor to be saved in each iteration of the MCMC algorithm. As this potentially requires much memory, the current implementation of `compute_mallows` saves these cluster probabilities to a csv file in each iteration. The example below shows how to perform such a check for label switching in practice.

Beware that this functionality is under development. Later releases might let the user determine the directory and filenames of the csv files.

References

Papastamoulis P (2016). "label.switching: An R Package for Dealing with the Label Switching Problem in MCMC Outputs." *Journal of Statistical Software, Code Snippets*, **69**(1), 1–24. ISSN 1548-7660, doi: 10.18637/jss.v069.c01, https://www.jstatsoft.org/v069/c01.

Stephens M (2000). "Dealing with label switching in mixture models." *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **62**(4), 795-809. doi: 10.1111/14679868.00265, https://rss.onlinelibrary.wiley.com/doi/abs/10.1111/1467-9868.00265.

Examples

```
## Not run:
  # This example shows how to assess if label switching happens in BayesMallows

  library(BayesMallows)
  # We start by creating a directory in which csv files with individual
  # cluster probabilities should be saved in each step of the MCMC algorithm
  dir.create("./test_label_switch")
  # Next, we go into this directory
  setwd("./test_label_switch/")
  # For comparison, we run compute_mallows with and without saving the cluster
  # probabilities The purpose of this is to assess the time it takes to save
  # the cluster probabilites
  system.time(m <- compute_mallows(rankings = sushi_rankings,
                                   n_clusters = 6, nmc = 2000, save_clus = TRUE,
                                   save_ind_clus = FALSE))
  # With this options, compute_mallows will save cluster_probs2.csv,
  # cluster_probs3.csv, ..., cluster_probs[nmc].csv.
  system.time(m <- compute_mallows(rankings = sushi_rankings, n_clusters = 6,
                                   nmc = 2000, save_clus = TRUE,
                                   save_ind_clus = TRUE))
```

```
# Next, we check convergence of alpha
assess_convergence(m)

# We set the burnin to 1000
burnin <- 1000

# Find all files that were saved. Note that the first file saved is cluster_probs2.csv
cluster_files <- list.files(pattern = "cluster\_probs[[:digit:]]+\\.csv")

# Check the size of the files that were saved.
paste(sum(do.call(file.size, list(cluster_files))) * 1e-6, "MB")

# Find the iteration each file corresponds to, by extracting its number
library(stringr)
iteration_number <- as.integer(str_extract(cluster_files, "[:digit:]+"))
# Remove all files before burnin
file.remove(cluster_files[iteration_number <= burnin])
# Update the vector of files, after the deletion
cluster_files <- list.files(pattern = "cluster\_probs[[:digit:]]+\\.csv")
# Create 3d array, with dimensions (iterations, assessors, clusters)
prob_array <- array(dim = c(length(cluster_files), m$n_assessors, m$n_clusters))
# Read each file, adding to the right element of the array
library(readr)
for(i in seq_along(cluster_files)){
  prob_array[i, , ] <- as.matrix(
    read_delim(cluster_files[[i]], delim = ",",
               col_names = FALSE, col_types = paste(rep("d", m$n_clusters),
                                                    collapse = "")))
}

library(dplyr)
library(tidyr)
# Create an tnteger array of latent allocations, as this is required by label.switching
z <- m$cluster_assignment %>%
  filter(iteration > burnin) %>%
  mutate(value = as.integer(str_extract(value, "[:digit:]+"))) %>%
  spread(key = assessor, value = value, sep = "_") %>%
  select(-iteration) %>%
  as.matrix()

# Now apply Stephen's algorithm
library(label.switching)
ls <- label.switching("STEPHENS", z = z, K = m$n_clusters, p = prob_array)

# Check the proportion of cluster assignments that were switched
mean(apply(ls$permutations$STEPHENS, 1, function(x) !all.equal(x, seq(1, m$n_clusters))))

# Remove the rest of the csv files
file.remove(cluster_files)
# Move up one directory
setwd("..")
# Remove the directory in which the csv files were saved
```

```
  file.remove("./test_label_switch/")

## End(Not run)
```

`plot.BayesMallows` *Plot Posterior Distributions*

Description

Plot posterior distributions of the parameters of the Mallows Rank model.

Usage

```
## S3 method for class 'BayesMallows'
plot(x, burnin = x$burnin, parameter = "alpha", items = NULL, ...)
```

Arguments

`x`	An object of type `BayesMallows`, returned from `compute_mallows`.
`burnin`	A numeric value specifying the number of iterations to discard as burn-in. Defaults to `x$burnin`, and must be provided if `x$burnin` does not exist. See `assess_convergence`.
`parameter`	Character string defining the parameter to plot. Available options are `"alpha"`, `"rho"`, `"cluster_probs"`, `"cluster_assignment"`, and `"theta"`.
`items`	The items to study in the diagnostic plot for `rho`. Either a vector of item names, corresponding to `x$items` or a vector of indices. If NULL, five items are selected randomly. Only used when `parameter = "rho"`.
`...`	Other arguments passed to `plot` (not used).

Examples

```
# The example datasets potato_visual and potato_weighing contain complete
# rankings of 20 items, by 12 assessors. We first analyse these using the Mallows
# model:
model_fit <- compute_mallows(potato_visual)

# Se the documentation to compute_mallows for how to assess the convergence
# of the algorithm
# We set the burnin = 1000
model_fit$burnin <- 1000
# By default, the scale parameter "alpha" is plotted
plot(model_fit)
## Not run:
  # We can also plot the latent rankings "rho"
  plot(model_fit, parameter = "rho")
  # By default, a random subset of 5 items are plotted
  # Specify which items to plot in the items argument.
  plot(model_fit, parameter = "rho",
```

```
      items = c(2, 4, 6, 9, 10, 20))
  # When the ranking matrix has column names, we can also
  # specify these in the items argument.
  # In this case, we have the following names:
  colnames(potato_visual)
  # We can therefore get the same plot with the following call:
  plot(model_fit, parameter = "rho",
      items = c("P2", "P4", "P6", "P9", "P10", "P20"))

## End(Not run)

## Not run:
  # Plots of mixture parameters:
  # We can run a mixture of Mallows models, using the n_clusters argument
 # We use the sushi example data. See the documentation of compute_mallows for a more elaborate
  # example
  model_fit <- compute_mallows(sushi_rankings, n_clusters = 5, save_clus = TRUE)
  model_fit$burnin <- 1000
  # We can then plot the posterior distributions of the cluster probabilities
  plot(model_fit, parameter = "cluster_probs")
  # We can also get a cluster assignment plot, showing the assessors along the horizontal
  # axis and the clusters along the vertical axis. The color show the probability
  # of belonging to each clusters. The assessors are sorted along the horizontal
  # axis according to their maximum a posterior cluster assignment. This plot
  # illustrates the posterior uncertainty in cluster assignments.
  plot(model_fit, parameter = "cluster_assignment")
  # See also ?assign_cluster for a function which returns the cluster assignment
  # back in a dataframe.

## End(Not run)
```

`plot_elbow` *Plot Within-Cluster Sum of Distances*

Description

Plot the within-cluster sum of distances from the corresponding cluster consensus for different number of clusters. This function is useful for selecting the number of mixture.

Usage

```
plot_elbow(..., burnin = NULL)
```

Arguments

...	One or more objects returned from compute_mallows, separated by comma, or a list of such objects. Typically, each object has been run with a different number of mixtures, as specified in the n_clusters argument to compute_mallows.
burnin	The number of iterations to discard as burnin. Either a vector of numbers, one for each model, or a single number which is taken to be the burnin for all models. If each model provided has a burnin element, then this is taken as the default.

Value

A boxplot with the number of clusters on the horizontal axis and the with-cluster sum of distances on the vertical axis.

See Also

compute_mallows

Examples

```
# DETERMINING THE NUMBER OF CLUSTERS IN THE SUSHI EXAMPLE DATA
## Not run:
  # Let us look at any number of clusters from 1 to 10
  # We use the convenience function compute_mallows_mixtures
  n_clusters <- seq(from = 1, to = 10)
  models <- compute_mallows_mixtures(n_clusters = n_clusters,
                                     rankings = sushi_rankings,
                                     include_wcd = TRUE)
  # models is a list in which each element is an object of class BayesMallows,
  # returned from compute_mallows
  # We can create an elbow plot
  plot_elbow(models, burnin = 1000)
  # We then select the number of cluster at a point where this plot has
  # an "elbow", e.g., n_clusters = 5.

  # Having chosen the number of clusters, we can now study the final model
  # Rerun with 5 clusters, now setting save_clus = TRUE to get cluster assignments
  mixture_model <- compute_mallows(rankings = sushi_rankings, n_clusters = 5,
                                   include_wcd = TRUE, save_clus = TRUE)
  # Delete the models object to free some memory
  rm(models)
  # Set the burnin
  mixture_model$burnin <- 1000
  # Plot the posterior distributions of alpha per cluster
  plot(mixture_model)
  # Compute the posterior interval of alpha per cluster
  compute_posterior_intervals(mixture_model,
                              parameter = "alpha")
  # Plot the posterior distributions of cluster probabilities
  plot(mixture_model, parameter = "cluster_probs")
  # Plot the posterior probability of cluster assignment
  plot(mixture_model, parameter = "cluster_assignment")
```

```
  # Plot the posterior distribution of "tuna roll" in each cluster
  plot(mixture_model, parameter = "rho", items = "tuna roll")
  # Compute the cluster-wise CP consensus, and show one column per cluster
  cp <- compute_consensus(mixture_model, type = "CP")
  library(dplyr)
  library(tidyr)
  cp %>%
    select(-cumprob) %>%
    spread(key = cluster, value = item)
  # Compute the MAP consensus, and show one column per cluster
  map <- compute_consensus(mixture_model, type = "MAP")
  map %>%
    select(-probability) %>%
    spread(key = cluster, value = item)

  # RUNNING IN PARALLEL
  # Computing Mallows models with different number of mixtures in parallel leads to
  # considerably speedup
  library(parallel)
  cl <- makeCluster(detectCores() - 1)
  n_clusters <- seq(from = 1, to = 10)
  models <- compute_mallows_mixtures(n_clusters = n_clusters,
                                     rankings = sushi_rankings,
                                     include_wcd = TRUE, cl = cl)
  stopCluster(cl)

## End(Not run)
```

---

plot_top_k *Plot Top-k Rankings with Pairwise Preferences*

Description

Plot the posterior probability, per item, of being ranked among the top-k for each assessor. This plot is useful when the data take the form of pairwise preferences.

Usage

```
plot_top_k(
  model_fit,
  burnin = model_fit$burnin,
  k = 3,
  rel_widths = c(rep(1, model_fit$n_clusters), 10)
)
```

Arguments

model_fit	An object of type BayesMallows, returned from compute_mallows.
burnin	A numeric value specifying the number of iterations to discard as burn-in. Defaults to model_fit$burnin, and must be provided if model_fit$burnin does not exist. See assess_convergence.
k	Integer specifying the k in top-k.
rel_widths	The relative widths of the plots of rho per cluster and the plot of assessors, respectively. This argument is passed on to plot_grid.

See Also

predict_top_k

Examples

```
## Not run:
  # We use the example dataset with beach preferences. Se the documentation to
  # compute_mallows for how to assess the convergence of the algorithm
  # We need to save the augmented data, so setting this option to TRUE
  model_fit <- compute_mallows(preferences = beach_preferences,
                               save_aug = TRUE)
  # We set burnin = 1000
  model_fit$burnin <- 1000
  # By default, the probability of being top-3 is plotted
  plot_top_k(model_fit)
  # We can also plot the probability of being top-5, for each item
  plot_top_k(model_fit, k = 5)
  # We get the underlying numbers with predict_top_k
  probs <- predict_top_k(model_fit)
  # To find all items ranked top-3 by assessors 1-3 with probability more than 80 %,
  # we do
  library(dplyr)
  probs %>%
    filter(assessor %in% 1:3, prob > 0.8)


## End(Not run)
```

---

potato_true_ranking *True ranking of the weights of 20 potatoes.*

Description

True ranking of the weights of 20 potatoes.

Usage

```
potato_true_ranking
```

Format

An object of class `numeric` of length 20.

References

Liu Q, Crispino M, Scheel I, Vitelli V, Frigessi A (2019). "Model-Based Learning from Preference Data." *Annual Review of Statistics and Its Application*, **6**(1). doi: 10.1146/annurevstatistics031017-100213.

`potato_visual` *Result of ranking potatoes by weight, where the assessors were only allowed to inspected the potatoes visually. 12 assessors ranked 20 potatoes.*

Description

Result of ranking potatoes by weight, where the assessors were only allowed to inspected the potatoes visually. 12 assessors ranked 20 potatoes.

Usage

```
potato_visual
```

Format

An object of class `matrix` (inherits from `array`) with 12 rows and 20 columns.

References

Liu Q, Crispino M, Scheel I, Vitelli V, Frigessi A (2019). "Model-Based Learning from Preference Data." *Annual Review of Statistics and Its Application*, **6**(1). doi: 10.1146/annurevstatistics031017-100213.

`potato_weighing` *Result of ranking potatoes by weight, where the assessors were allowed to lift the potatoes. 12 assessors ranked 20 potatoes.*

Description

Result of ranking potatoes by weight, where the assessors were allowed to lift the potatoes. 12 assessors ranked 20 potatoes.

Usage

```
potato_weighing
```

Format

An object of class `matrix` (inherits from `array`) with 12 rows and 20 columns.

References

Liu Q, Crispino M, Scheel I, Vitelli V, Frigessi A (2019). "Model-Based Learning from Preference Data." *Annual Review of Statistics and Its Application*, **6**(1). doi: 10.1146/annurevstatistics031017-100213.

`predict_top_k` *Predict Top-k Rankings with Pairwise Preferences*

Description

Predict the posterior probability, per item, of being ranked among the top-k for each assessor. This is useful when the data take the form of pairwise preferences.

Usage

```
predict_top_k(model_fit, burnin = model_fit$burnin, k = 3)
```

Arguments

`model_fit`	An object of type `BayesMallows`, returned from `compute_mallows`.
`burnin`	A numeric value specifying the number of iterations to discard as burn-in. Defaults to `model_fit$burnin`, and must be provided if `model_fit$burnin` does not exist. See `assess_convergence`.
`k`	Integer specifying the k in top-k.

Value

A dataframe with columns `assessor`, `item`, and `prob`, where each row states the probability that the given assessor rates the given item among top-k.

See Also

`plot_top_k`

print.BayesMallows *Print Method for BayesMallows Objects*

Description

The default print method for a BayesMallows object.

Usage

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

Arguments

x	An object of type BayesMallows, returned from compute_mallows.
...	Other arguments passed to print (not used).

print.BayesMallowsMixtures *Print Method for BayesMallowsMixtures Objects*

Description

The default print method for a BayesMallowsMixtures object.

Usage

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

Arguments

x	An object of type BayesMallowsMixtures, returned from compute_mallows_mixtures.
...	Other arguments passed to print (not used).

rank_conversion *Convert between ranking and ordering.*

Description

create_ranking takes a vector or matrix of ordered items orderings and returns a corresponding vector or matrix of ranked items. create_ordering takes a vector or matrix of rankings rankings and returns a corresponding vector or matrix of ordered items.

Usage

```
create_ranking(orderings)

create_ordering(rankings)
```

Arguments

orderings	A vector or matrix of ordered items. If a matrix, it should be of size N times n, where N is the number of samples and n is the number of items.
rankings	A vector or matrix of ranked items. If a matrix, it should be N times n, where N is the number of samples and n is the number of items.

Value

A vector or matrix of rankings. Missing orderings coded as NA are propagated into corresponding missing ranks and vice versa.

Functions

- create_ranking: Convert from ordering to ranking.
- create_ordering: Convert from ranking to ordering.

Examples

```
# A vector of ordered items.
orderings <- c(5, 1, 2, 4, 3)
# Get ranks
rankings <- create_ranking(orderings)
# rankings is c(2, 3, 5, 4, 1)
# Finally we convert it backed to an ordering.
orderings_2 <- create_ordering(rankings)
# Confirm that we get back what we had
all.equal(orderings, orderings_2)

# Next, we have a matrix with N = 19 samples
# and n = 4 items
set.seed(21)
N <- 10
```

```
n <- 4
orderings <- t(replicate(N, sample.int(n)))
# Convert the ordering to ranking
rankings <- create_ranking(orderings)
# Now we try to convert it back to an ordering.
orderings_2 <- create_ordering(rankings)
# Confirm that we get back what we had
all.equal(orderings, orderings_2)
```

`sample_mallows` *Random Samples from the Mallows Rank Model*

Description

Generate random samples from the Mallows Rank Model (Mallows 1957) with consensus ranking ρ and scale parameter α. The samples are obtained by running the Metropolis-Hastings algorithm described in Appendix C of Vitelli et al. (2018).

Usage

```
sample_mallows(
  rho0,
  alpha0,
  n_samples,
  leap_size = 1,
  metric = "footrule",
  diagnostic = FALSE,
  burnin = ifelse(diagnostic, 0, 1000),
  thinning = ifelse(diagnostic, 1, 1000),
  items_to_plot = NULL,
  max_lag = 1000L
)
```

Arguments

`rho0`	Vector specifying the latent consensus ranking in the Mallows rank model.
`alpha0`	Scalar specifying the scale parameter in the Mallows rank model.
`n_samples`	Integer specifying the number of random samples to generate. When `diagnostic = TRUE`, this number must be larger than 1.
`leap_size`	Integer specifying the step size of the leap-and-shift proposal distribution.
`metric`	Character string specifying the distance measure to use. Available options are `"footrule"` (default), `"spearman"`, `"cayley"`, `"hamming"`, `"kendall"`, and `"ulam"`. See also the `rmm` function in the `PerMallows` package (Irurozki et al. 2016) for sampling from the Mallows model with Cayley, Hamming, Kendall, and Ulam distances.
`diagnostic`	Logical specifying whether to output convergence diagnostics. If `TRUE`, a diagnostic plot is printed, together with the returned samples.

burnin	Integer specifying the number of iterations to discard as burn-in. Defaults to 1000 when diagnostic = FALSE, else to 0.
thinning	Integer specifying the number of MCMC iterations to perform between each time a random rank vector is sampled. Defaults to 1000 when diagnostic = FALSE, else to 1.
items_to_plot	Integer vector used if diagnostic = TRUE, in order to specify the items to plot in the diagnostic output. If not provided, 5 items are picked at random.
max_lag	Integer specifying the maximum lag to use in the computation of autocorrelation. Defaults to 1000L. This argument is passed to stats::acf. Only used when diagnostic = TRUE.

References

Irurozki E, Calvo B, Lozano JA (2016). "PerMallows: An R Package for Mallows and Generalized Mallows Models." *Journal of Statistical Software*, **71**(12), 1–30. doi: 10.18637/jss.v071.i12.

Mallows CL (1957). "Non-Null Ranking Models. I." *Biometrika*, **44**(1/2), 114–130.

Vitelli V, Sørensen Ø, Crispino M, Arjas E, Frigessi A (2018). "Probabilistic Preference Learning with the Mallows Rank Model." *Journal of Machine Learning Research*, **18**(1), 1–49. http://jmlr.org/papers/v18/15-481.html.

Examples

```
# Sample 100 random rankings from a Mallows distribution with footrule distance
set.seed(1)
# Number of items
n_items <- 15
# Set the consensus ranking
rho0 <- seq(from = 1, to = n_items, by = 1)
# Set the scale
alpha0 <- 10
# Number of samples
n_samples <- 100
# We first do a diagnostic run, to find the thinning and burnin to use
# We set n_samples to 1000, in order to run 1000 diagnostic iterations.
test <- sample_mallows(rho0 = rho0, alpha0 = alpha0, diagnostic = TRUE,
                       n_samples = 1000, burnin = 1, thinning = 1)
# When items_to_plot is not set, 5 items are picked at random. We can change this.
# We can also reduce the number of lags computed in the autocorrelation plots
test <- sample_mallows(rho0 = rho0, alpha0 = alpha0, diagnostic = TRUE,
                       n_samples = 1000, burnin = 1, thinning = 1,
                       items_to_plot = c(1:3, 10, 15), max_lag = 500)
# From the autocorrelation plot, it looks like we should use
# a thinning of at least 200. We set thinning = 1000 to be safe,
# since the algorithm in any case is fast. The Markov Chain
# seems to mix quickly, but we set the burnin to 1000 to be safe.
# We now run sample_mallows again, to get the 100 samples we want:
samples <- sample_mallows(rho0 = rho0, alpha0 = alpha0, n_samples = 100,
                          burnin = 1000, thinning = 1000)
```

```
# The samples matrix now contains 100 rows with rankings of 15 items.
# A good diagnostic, in order to confirm that burnin and thinning are set high
# enough, is to run compute_mallows on the samples
model_fit <- compute_mallows(samples, nmc = 10000)
# The highest posterior density interval covers alpha0 = 10.
compute_posterior_intervals(model_fit, burnin = 2000, parameter = "alpha")

# The PerMallows package has a Gibbs sampler for sampling from the Mallows
# distribution with Cayley, Kendall, Hamming, and Ulam distances. For these
# distances, using the PerMallows package is typically faster.

# Let us sample 100 rankings from the Mallows model with Cayley distance,
# with the same consensus ranking and scale parameter as above.
library(PerMallows)
# Set the scale parameter of the PerMallows package corresponding to
# alpha0 in BayesMallows
theta0 = alpha0 / n_items
# Sample with PerMallows::rmm
sample1 <- rmm(n = 100, sigma0 = rho0, theta = theta0, dist.name = "cayley")
# Generate the same sample with sample_mallows
sample2 <- sample_mallows(rho0 = rho0, alpha0 = alpha0, n_samples = 100,
                          burnin = 1000, thinning = 1000, metric = "cayley")
```

`sushi_rankings` *Sushi Rankings*

Description

Complete rankings of 10 types of sushi from 5000 assessors (Kamishima 2003).

Usage

```
sushi_rankings
```

Format

An object of class `matrix` (inherits from `array`) with 5000 rows and 10 columns.

References

Kamishima T (2003). "Nantonac Collaborative Filtering: Recommendation Based on Order Responses." In *Proceedings of the Ninth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 583–588.

Index