Package 'EMC2'

March 10, 2025

Title Bayesian Hierarchical Analysis of Cognitive Models of Choice

Version 3.1.0

Description Fit Bayesian (hierarchical) cognitive models
using a linear modeling language interface using particle Metropolis Markov
chain Monte Carlo sampling with Gibbs steps. The diffusion decision model (DDM),
linear ballistic accumulator model (LBA), racing diffusion model (RDM), and the lognormal
race model (LNR) are supported. Additionally, users can specify their own likelihood
function and/or choose for non-hierarchical
estimation, as well as for a diagonal, blocked or full multivariate normal
group-level distribution to test individual differences. Prior specification
is facilitated through methods that visualize the (implied) prior.
A wide range of plotting functions assist in assessing model convergence and
posterior inference. Models can be easily evaluated using functions
that plot posterior predictions or using relative model comparison metrics
such as information criteria or Bayes factors.
References: Stevenson et al. (2024) <doi:10.31234/osf.io/2e4dq>.

License GPL (>= 3)

URL https://ampl-psych.github.io/EMC2/,
https://github.com/ampl-psych/EMC2

BugReports https://github.com/ampl-psych/EMC2/issues

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Contents

`auto_thin.emc` *Automatically Thin an emc Object*

Description

Uses the effective sample size of `selection` to determine how much to optimally thin an emc object

Usage

```
## S3 method for class 'emc'
auto_thin(emc, stage = "sample", selection = c("alpha", "mu"), ...)

auto_thin(emc, stage = "sample", selection = c("alpha", "mu"), ...)
```

Arguments

emc	an emc object.
stage	A character string. Indicates from which sampling stage(s) to take the samples from (i.e. preburn, burn, adapt, sample)
selection	Which parameter types (i.e. 'alpha' or 'mu' to consider when determining the effective sample size)
...	additional optional arguments

---

chain_n *MCMC Chain Iterations*

Description

Returns a matrix with the number of samples per chain for each stage that is present in the emc object (i.e., preburn, burn, adapt, sample). The number of rows of the matrix reflects the number of chains and the number of columns the number of sampling stages.

Usage

```
chain_n(emc)
```

Arguments

emc	A list, the output of fit().

Value

A matrix

Examples

```
chain_n(samples_LNR)
```

check.emc *Convergence Checks for an emc Object*

Description

Runs a series of convergence checks, prints statistics to the console, and makes traceplots of the worst converged parameter per selection.

Usage

```
## S3 method for class 'emc'
check(
  emc,
  selection = c("mu", "sigma2", "alpha"),
  digits = 3,
  plot_worst = TRUE,
  ...
)

check(emc, ...)
```

Arguments

emc	An emc object
selection	A Character vector. Indicates which parameter types to check (e.g., alpha, mu, sigma2, correlation).
digits	Integer. How many digits to round the ESS and Rhat to in the plots
plot_worst	Boolean. If TRUE also plots the chain plots for the worst parameter
...	Optional arguments that can be passed to get_pars or plot.default (see par())

Details

Note that the Rhat is calculated by doubling the number of chains by first splitting chains into first and second half, so it also a test of stationarity.

Efficiency of sampling is indicated by the effective sample size (ESS) (from the coda R package). Full range of possible samples manipulations described in get_pars.

Value

a list with the statistics for the worst converged parameter per selection

Examples

```
check(samples_LNR)
```

compare *Information Criteria and Marginal Likelihoods*

Description

Returns the BPIC/DIC or marginal deviance (-2*marginal likelihood) for a list of samples objects.

Usage

```
compare(
  sList,
  stage = "sample",
  filter = NULL,
  use_best_fit = TRUE,
  BayesFactor = TRUE,
  cores_for_props = 4,
  cores_per_prop = 1,
  print_summary = TRUE,
  digits = 0,
  digits_p = 3,
  ...
)
```

Arguments

sList	List of samples objects
stage	A string. Specifies which stage the samples are to be taken from "preburn", "burn", "adapt", or "sample"
filter	An integer or vector. If it's an integer, iterations up until the value set by filter will be excluded. If a vector is supplied, only the iterations in the vector will be considered.
use_best_fit	Boolean, defaults to TRUE, uses the minimal or mean likelihood (whichever is better) in the calculation, otherwise always uses the mean likelihood.
BayesFactor	Boolean, defaults to TRUE. Include marginal likelihoods as estimated using WARP-III bridge sampling. Usually takes a minute per model added to calculate
cores_for_props	Integer, how many cores to use for the Bayes factor calculation, here 4 is the default for the 4 different proposal densities to evaluate, only 1, 2 and 4 are sensible.
cores_per_prop	Integer, how many cores to use for the Bayes factor calculation if you have more than 4 cores available. Cores used will be cores_for_props * cores_per_prop. Best to prioritize cores_for_props being 4 or 2
print_summary	Boolean (default TRUE), print table of results
digits	Integer, significant digits in printed table for information criteria
digits_p	Integer, significant digits in printed table for model weights
...	Additional, optional arguments

Value

Matrix of effective number of parameters, mean deviance, deviance of mean, DIC, BPIC, Marginal Deviance (if `BayesFactor=TRUE`) and associated weights.

Examples

```
compare(list(samples_LNR), cores_for_props = 1)
# Typically we would define a list of two (or more) different models:
# # Here the full model is an emc object with the hypothesized effect
# # The null model is an emc object without the hypothesized effect
# design_full <- design(data = forstmann,model=DDM,
#                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
#                           constants=c(s=log(1)))
# # Now without a ~ E
# design_null <- design(data = forstmann,model=DDM,
#                           formula =list(v~0+S,a~1, t0~1, s~1, Z~1, sv~1, SZ~1),
#                           constants=c(s=log(1)))
#
# full_model <- make_emc(forstmann, design_full)
# full_model <- fit(full_model)
#
# null_model <- make_emc(forstmann, design_null)
# null_model <- fit(null_model)
# sList <- list(full_model, null_model)
# # By default emc uses 4 cores to parallelize marginal likelihood estimation across proposals
# # So cores_per_prop = 3 results in 12 cores used.
# compare(sList, cores_per_prop = 3)
```

---

compare_subject *Information Criteria For Each Participant*

Description

Returns the BPIC/DIC based model weights for each participant in a list of samples objects

Usage

```
compare_subject(
  sList,
  stage = "sample",
  filter = 0,
  use_best_fit = TRUE,
  print_summary = TRUE,
  digits = 3
)
```

Arguments

sList	List of samples objects
stage	A string. Specifies which stage the samples are to be taken from "preburn", "burn", "adapt", or "sample"
filter	An integer or vector. If it's an integer, iterations up until the value set by filter will be excluded. If a vector is supplied, only the iterations in the vector will be considered.
use_best_fit	Boolean, defaults to TRUE, use minimal likelihood or mean likelihood (whichever is better) in the calculation, otherwise always uses the mean likelihood.
print_summary	Boolean (defaults to TRUE) print table of results
digits	Integer, significant digits in printed table

Value

List of matrices for each subject of effective number of parameters, mean deviance, deviance of mean, DIC, BPIC and associated weights.

Examples

```
# For a broader illustration see `compare`.
# Here we just take two times the same model, but normally one would compare
# different models
compare_subject(list(m0 = samples_LNR, m1 = samples_LNR))
```

---

contr.anova *Anova Style Contrast Matrix*

Description

Similar to contr.helmert, but then scaled to estimate differences between conditions. Use in design().

Usage

```
contr.anova(n)
```

Arguments

n	An integer. The number of items for which to create the contrast

Value

A contrast matrix.

Examples

```
{
design_DDMaE <- design(data = forstmann,model=DDM, contrasts = list(E = contr.anova),
formula =list(v~S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
constants=c(s=log(1)))
}
```

`contr.bayes` *Contrast Enforcing Equal Prior Variance on each Level*

Description

Typical contrasts impose different levels of marginal prior variance for the different levels. This contrast can be used to ensure that each level has equal marginal priors (Rouder, Morey, Speckman, & Province; 2012).

Usage

```
contr.bayes(n)
```

Arguments

`n`	An integer. The number of items for which to create the contrast

Value

A contrast matrix.

Examples

```
{
design_DDMaE <- design(data = forstmann,model=DDM, contrasts = list(E = contr.bayes),
formula =list(v~S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
constants=c(s=log(1)))
}
```

`contr.decreasing` *Contrast Enforcing Decreasing Estimates*

Description

Each level will be estimated as a reduction from the previous level

Usage

```
contr.decreasing(n)
```

Arguments

n	an integer. The number of items for which to create the contrast.

Value

a contrast matrix.

Examples

```
{
design_DDMaE <- design(data = forstmann,model=DDM, contrasts = list(E = contr.decreasing),
formula =list(v~S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
constants=c(s=log(1)))
}
```

---

contr.increasing *Contrast Enforcing Increasing Estimates*

Description

Each level will be estimated additively from the previous level

Usage

```
contr.increasing(n)
```

Arguments

n	an integer. The number of items for which to create the contrast.

Value

a contrast matrix.

Examples

```
{
design_DDMaE <- design(data = forstmann,model=DDM, contrasts = list(E = contr.increasing),
formula =list(v~S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
constants=c(s=log(1)))
}
```

credible.emc *Posterior Credible Interval Tests*

Description

Modeled after `t.test`, returns the credible interval of the parameter or test and what proportion of the posterior distribution (or the difference in posterior distributions in case of a two sample test) overlaps with mu. For a one sample test provide `x` and for two sample also provide `y`. Note that for comparisons within one model, we recommend using `hypothesis()` if the priors were well chosen.

Usage

```
## S3 method for class 'emc'
credible(
  x,
  x_name = NULL,
  x_fun = NULL,
  x_fun_name = "fun",
  selection = "mu",
  y = NULL,
  y_name = NULL,
  y_fun = NULL,
  y_fun_name = "fun",
  x_subject = NULL,
  y_subject = NULL,
  mu = 0,
  alternative = c("less", "greater")[1],
  probs = c(0.025, 0.5, 0.975),
  digits = 2,
  p_digits = 3,
  print_table = TRUE,
  ...
)

credible(x, ...)
```

Arguments

`x`	An emc object
`x_name`	A character string. Name of the parameter to be tested for `x`
`x_fun`	Function applied to the MCMC chains to create variable to be tested.
`x_fun_name`	Name to give to quantity calculated by `x_fun`
`selection`	A character string designating parameter type (e.g. `alpha` or `covariance`)
`y`	A second emc object
`y_name`	A character string. Name of the parameter to be tested for `y`

y_fun	Function applied to the MCMC chains to create variable to be tested.
y_fun_name	Name to give to quantity calculated by y_fun
x_subject	Integer or name selecting a subject
y_subject	Integer or name selecting a subject
mu	Numeric. NULL value for single sample test if y is not supplied (default 0)
alternative	less or greater determining direction of test probability
probs	Vector defining quantiles to return.
digits	Integer, significant digits for estimates in printed results
p_digits	Integer, significant digits for probability in printed results
print_table	Boolean (defaults to TRUE) for printing results table
...	Additional optional arguments that can be passed to get_pars

Value

Invisible results table with no rounding.

Examples

```
{
# Run a credible interval test (Bayesian ''t-test'')
credible(samples_LNR, x_name = "m")
# We can also compare between two sets of emc objects

# # Now without a ~ E
# design_null <- design(data = forstmann,model=DDM,
#                            formula =list(v~0+S,a~1, t0~1, s~1, Z~1, sv~1, SZ~1),
#                            constants=c(s=log(1)))
#
# null_model <- make_emc(forstmann, design_null)
# null_model <- fit(null_model)
# credible(x = null_model, x_name = "a", y = full_model, y_name = "a")
#
# # Or provide custom functions:
# credible(x = full_model, x_fun = function(d) d["a_Eaccuracy"] - d["a_Eneutral"])
}
```

---

credint.emc.prior *Posterior Quantiles*

Description

Returns the quantiles of the selected parameter type. Full range of possible samples manipulations described in get_pars.

Usage

```
## S3 method for class 'emc.prior'
credint(
  x,
  selection = "mu",
  probs = c(0.025, 0.5, 0.975),
  digits = 3,
  N = 1000,
  covariates = NULL,
  ...
)

## S3 method for class 'emc'
credint(x, selection = "mu", probs = c(0.025, 0.5, 0.975), digits = 3, ...)

credint(x, ...)
```

Arguments

x	An emc or emc.prior object
selection	A Character vector. Indicates which parameter types to check (e.g., alpha, mu, sigma2, correlation).
probs	A vector. Indicates which quantiles to return from the posterior.
digits	Integer. How many digits to round the output to
N	An integer. Number of samples to use for the quantile calculation (only for prior.emc objects)
covariates	A list of covariates to use for the quantile calculation (only for prior.emc objects)
...	Optional additional arguments that can be passed to get_pars

Value

A list of posterior quantiles for each parameter group in the selected parameter type.

Examples

```
credint(samples_LNR)
```

DDM *The Diffusion Decision Model*

Description

Model file to estimate the Diffusion Decision Model (DDM) in EMC2.

Usage

```
DDM()
```

Details

Model files are almost exclusively used in `design()`.

Default values are used for all parameters that are not explicitly listed in the `formula` argument of `design()`.They can also be accessed with `DDM()$p_types`.

Parameter	Transform	Natural scale	Default	Mapping	Interpretation
v	-	[-Inf, Inf]	1		Mean evidence-accumulation
a	log	[0, Inf]	log(1)		Boundary separation
t0	log	[0, Inf]	log(0)		Non-decision time
s	log	[0, Inf]	log(1)		Within-trial standard deviatio
Z	probit	[0, 1]	qnorm(0.5)	$z = Z \times a$	Relative start point (bias)
SZ	probit	[0, 1]	qnorm(0)	$sz = 2 \times SZ \times \min(a \times Z, a \times (1\text{-}Z))$	Relative between-trial variati
sv	log	[0, Inf]	log(0)		Between-trial standard deviat
st0	log	[0, Inf]	log(0)		Between-trial variation (rang

`a`, `t0`, `sv`, `st0`, `s` are sampled on the log scale because these parameters are strictly positive, `Z`, `SZ` and `DP` are sampled on the probit scale because they should be strictly between 0 and 1.

`Z` is estimated as the ratio of bias to one boundary where 0.5 means no bias. `DP` comprises the difference in non-decision time for each response option.

Conventionally, `s` is fixed to 1 to satisfy scaling constraints.

See Ratcliff, R., & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. *Neural computation, 20*(4), 873-922. doi:10.1162/neco.2008.12-06-420.

Value

A model list with all the necessary functions for EMC2 to sample

Examples

```
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# For all parameters that are not defined in the formula, default values are assumed
# (see Table above).
```

design *Specify a Design and Model*

Description

This function combines information regarding the data, type of model, and the model specification.

Usage

```
design(
  formula = NULL,
  factors = NULL,
  Rlevels = NULL,
  model,
  data = NULL,
  contrasts = NULL,
  matchfun = NULL,
  constants = NULL,
  covariates = NULL,
  functions = NULL,
  report_p_vector = TRUE,
  custom_p_vector = NULL,
  transform = NULL,
  bound = NULL,
  ...
)
```

Arguments

formula	A list. Contains the design formulae in the format `list(y ~ x, a ~ z)`.
factors	A named list containing all the factor variables that span the design cells and that should be taken into account by the model. The name `subjects` must be used to indicate the participant factor variable, also in the data. Example: `list(subjects=levels(dat$subjects), condition=levels(dat$condition))`
Rlevels	A character vector. Contains the response factor levels. Example: `c("right", "left")`
model	A function, specifies the model type. Choose from the drift diffusion model (`DDM()`, `DDMt0natural()`), the log-normal race model (`LNR()`), the linear ballistic model (`LBA()`), the racing diffusion model (`RDM()`, `RDMt0natural()`), or define your own model functions.
data	A data frame. `data` can be used to automatically detect `factors`, `Rlevels` and `covariates` in a dataset. The variable `R` needs to be a factor variable indicating the response variable. Any numeric column except `trials` and `rt` are treated as covariates, and all remaining factor variables are internally used in `factors`.
contrasts	Optional. A named list specifying a design matrix. Example for supplying a customized design matrix: `list(lM = matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"diff")))`

matchfun	A function. Only needed for race models. Specifies whether a response was correct or not. Example: function(d)d$S==d$lR where lR refers to the latent response factor.
constants	A named vector that sets constants. Any parameter in sampled_pars can be set constant.
covariates	Names of numeric covariates.
functions	List of functions to create new factors based on those in the factors argument. These new factors can then be used in formula.
report_p_vector	Boolean. If TRUE (default), it returns the vector of parameters to be estimated.
custom_p_vector	A character vector. If specified, a custom likelihood function can be supplied.
transform	A list with custom transformations to be applied to the parameters of the model, if the conventional transformations aren't desired. See DDM() for an example of such transformations
bound	A list with custom bounds to be applied to the parameters of the model, if the conventional bound aren't desired. see DDM() for an example of such bounds. Bounds are used to set limits to the likelihood landscape that cannot reasonable be achieved with transform
...	Additional, optional arguments

Value

A design list.

Examples

```
# load example dataset
dat <- forstmann

# create a function that takes the latent response (lR) factor (d) and returns a logical
# defining the correct response for each stimulus. Here the match is simply
# such that the S factor equals the latent response factor
matchfun <- function(d)d$S==d$lR

# When working with lM and lR, it can be useful to design  an
# "average and difference" contrast matrix. For binary responses, it has a
# simple canonical form
ADmat <- matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"diff"))

# Create a design for a linear ballistic accumulator model (LBA) that allows
# thresholds to be a function of E and lR. The final result is a 9 parameter model.
design_LBABE <- design(data = dat,model=LBA,matchfun=matchfun,
                           formula=list(v~lM,sv~lM,B~E+lR,A~1,t0~1),
                           contrasts=list(v=list(lM=ADmat)),
                           constants=c(sv=log(1)))
```

`ess_summary.emc` *Effective Sample Size*

Description

Returns the effective sample size (ESS) of the selected parameter type. Full range of possible samples manipulations described in `get_pars`.

Usage

```
## S3 method for class 'emc'
ess_summary(
  emc,
  selection = "mu",
  stat = "min",
  stat_only = FALSE,
  digits = 1,
  ...
)

ess_summary(emc, ...)
```

Arguments

`emc`	An emc object
`selection`	A Character vector. Indicates which parameter types to check (e.g., `alpha`, `mu`, `sigma2`, `correlation`).
`stat`	A string. Should correspond to a function that can be applied to a vector, which will be performed on the vector/rows or columns of the matrix of the parameters
`stat_only`	Boolean. If `TRUE` will only return the result of the applied stat function, otherwise returns both the stat result and the result of the function on all parameters.
`digits`	Integer. How many digits to round the output to
`...`	Optional additional arguments that can be passed to `get_pars`

Value

A matrix or vector of ESS values for the selected parameter type.

Examples

```
ess_summary(samples_LNR, selection = "alpha")
```

`fit.emc` *Model Estimation in EMC2*

Description

General purpose function to estimate models specified in EMC2.

Usage

```
## S3 method for class 'emc'
fit(
  emc,
  stage = NULL,
  iter = 1000,
  stop_criteria = NULL,
  report_time = TRUE,
  search_width = 1,
  step_size = 100,
  verbose = TRUE,
  verboseProgress = FALSE,
  fileName = NULL,
  particles = NULL,
  particle_factor = 50,
  cores_per_chain = 1,
  cores_for_chains = length(emc),
  max_tries = 20,
  thin_auto = FALSE,
  n_blocks = 1,
  ...
)

fit(emc, ...)
```

Arguments

`emc`	An emc object created with `make_emc`, or a path to where the emc object is stored.
`stage`	A string. Indicates which stage to start the run from, either `preburn`, `burn`, `adapt` or `sample`. If unspecified, it will run the subsequent stage (if there is one).
`iter`	An integer. Indicates how many iterations to run in the sampling stage.
`stop_criteria`	A list. Defines the stopping criteria and for which types of parameters these should hold. See the details and examples section.
`report_time`	Boolean. If `TRUE`, the time taken to run the MCMC chains till completion of the `stop_criteria` will be printed.

search_width — A double. Tunes target acceptance probability of the MCMC process. This fine-tunes the width of the search space to obtain the desired acceptance probability. 1 is the default width, increases lead to broader search.

step_size — An integer. After each step, the stopping requirements as specified by stop_criteria are checked and proposal distributions are updated. Defaults to 100.

verbose — Logical. Whether to print messages between each step with the current status regarding the stop_criteria.

verboseProgress — Logical. Whether to print a progress bar within each step or not. Will print one progress bar for each chain and only if cores_for_chains = 1.

fileName — A string. If specified, will auto-save emc object at this location on every iteration.

particles — An integer. How many particles to use, default is NULL and particle_factor is used instead. If specified, particle_factor is overwritten.

particle_factor — An integer. particle_factor multiplied by the square root of the number of sampled parameters determines the number of particles used.

cores_per_chain — An integer. How many cores to use per chain. Parallelizes across participant calculations. Only available on Linux or Mac OS. For Windows, only parallelization across chains (cores_for_chains) is available.

cores_for_chains — An integer. How many cores to use across chains. Defaults to the number of chains. The total number of cores used is equal to cores_per_chain * cores_for_chains.

max_tries — An integer. How many times should it try to meet the finish conditions as specified by stop_criteria? Defaults to 20. max_tries is ignored if the required number of iterations has not been reached yet.

thin_auto — A boolean. If TRUE will automatically thin the MCMC samples, closely matched to the ESS.

n_blocks — An integer. Number of blocks. Will block the parameter chains such that they are updated in blocks. This can be helpful in extremely tough models with a large number of parameters.

... — Additional optional arguments

Details

stop_criteria is either a list of lists with names of the stages, or a single list in which case its assumed to be for the sample stage (see examples). The potential stop criteria to be set are:

selection (character vector): For which parameters the stop_criteria should hold

mean_gd (numeric): The mean Gelman-Rubin diagnostic across all parameters in the selection

max_gd (numeric): The max Gelman-Rubin diagnostic across all parameters in the selection

min_unique (integer): The minimum number of unique samples in the MCMC chains across all parameters in the selection

`min_es` (integer): The minimum number of effective samples across all parameters in the selection

`omit_mpsrf` (Boolean): Whether to include the multivariate point-scale reduction factor in the Gelman-Rubin diagnostic. Default is `FALSE`.

`iter` (integer): The number of MCMC samples to collect.

The estimation is performed using particle-metropolis within-Gibbs sampling. For sampling details see:

Gunawan, D., Hawkins, G. E., Tran, M.-N., Kohn, R., & Brown, S. (2020). New estimation approaches for the hierarchical linear ballistic accumulator model. *Journal of Mathematical Psychology* ,96, 102368. doi.org/10.1016/j.jmp.2020.102368

Stevenson, N., Donzallaz, M. C., Innes, R. J., Forstmann, B., Matzke, D., & Heathcote, A. (2024). EMC2: An R Package for cognitive models of choice. doi.org/10.31234/osf.io/2e4dq

Value

An emc object

Examples

```
## Not run:
# First define a design
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# Then make the emc object, we've omitted a prior here for brevity so default priors will be used.
emc_forstmann <- make_emc(forstmann, design_DDMaE)

# With the emc object we can start sampling by simply calling fit
emc_forstmann <- fit(emc_forstmann, fileName = "intermediate_save_location.RData")

# For particularly hard models it pays off to increase the ``particle_factor``
# and, although to a lesser extent, increase ``search_width``.
emc_forstmann <- fit(emc_forstmann, particle_factor = 100, search_width = 1.5)

# Example of how to use the stop_criteria:
emc_forstmann <- fit(emc_forstmann, stop_criteria = list(mean_gd = 1.1, max_gd = 1.5,
            selection = c('alpha', 'sigma2'), omit_mpsrf = TRUE, min_es = 1000))
# In this case the stop_criteria are set for the sample stage, which will be
# run until the mean_gd < 1.1, the max_gd < 1.5 (omitting the multivariate psrf)
# and the effective sample size > 1000,
# for both the individual-subject parameters ("alpha")
# and the group-level variance parameters.

# For the unspecified stages in the ``stop_criteria`` the default values
# are assumed which are found in Stevenson et al. 2024 <doi.org/10.31234/osf.io/2e4dq>

# Alternatively, you can also specify the stop_criteria for specific stages by creating a
# nested list
emc_forstmann <- fit(emc_forstmann, stop_criteria = list("burn" = list(mean_gd = 1.1, max_gd = 1.5,
            selection = c('alpha')), "adapt" = list(min_unique = 100)))
```

```
## End(Not run)
```

`forstmann` *Forstmann et al.'s Data*

Description

A dataset containing the speed or accuracy manipulation for a Random Dot Motion experiment.

Usage

```
forstmann
```

Format

A data frame with 15818 rows and 5 variables:

E Factor with 3 levels for Speed, Accuracy and Neutral

R Factor with 2 levels for Left and Right responses

S Factor with 2 levels for Left and Right trials

rt reaction time for each trial as a double

subjects integer ID for each subject

Details

Details on the dataset can be found in the following paper:

Striatum and pre-SMA facilitate decision-making under time pressure

Birte U. Forstmann, Gilles Dutilh, Scott Brown, Jane Neumann, D. Yves von Cramon, K. Richard Ridderinkhof, Eric-Jan Wagenmakers.

Proceedings of the National Academy of Sciences Nov 2008, 105 (45) 17538-17542; DOI: 10.1073/pnas.0805903105

Source

https://www.pnas.org/doi/10.1073/pnas.0805903105

gd_summary.emc *Gelman-Rubin Statistic*

Description

Returns the Gelman-Rubin diagnostics (otherwise known as the R-hat) of the selected parameter type; i.e. the ratio of between to within MCMC chain variance.

Usage

```
## S3 method for class 'emc'
gd_summary(
  emc,
  selection = "mu",
  omit_mpsrf = TRUE,
  stat = "max",
  stat_only = FALSE,
  digits = 3,
  ...
)

gd_summary(emc, ...)
```

Arguments

emc	An emc object
selection	A Character vector. Indicates which parameter types to check (e.g., alpha, mu, sigma2, correlation).
omit_mpsrf	Boolean. If TRUE also returns the multivariate point scale reduction factor (see ?coda::gelman.diag).
stat	A string. Should correspond to a function that can be applied to a vector, which will be performed on the vector/rows or columns of the matrix of the parameters
stat_only	Boolean. If TRUE will only return the result of the applied stat function, otherwise returns both the stat result and the result of the function on all parameters.
digits	Integer. How many digits to round the output to
...	Optional additional arguments that can be passed to get_pars

Details

See: Gelman, A and Rubin, DB (1992) Inference from iterative simulation using multiple sequences, *Statistical Science*, 7, 457-511.

Full range of possible samples manipulations described in get_pars.

Value

A matrix or vector of R-hat values for the selected parameter type.

Examples

```
gd_summary(samples_LNR, selection = "correlation", stat = "mean", flatten = TRUE)
```

---

get_BayesFactor *Bayes Factors*

Description

returns the Bayes Factor for two models

Usage

```
get_BayesFactor(MLL1, MLL2)
```

Arguments

MLL1	Numeric. Marginal likelihood of model 1. Obtained with `run_bridge_sampling()`
MLL2	Numeric. Marginal likelihood of model 2. Obtained with `run_bridge_sampling()`

Value

The BayesFactor for model 1 over model 2

Examples

```
# Normally one would compare two different models
# Here we use two times the same model:
M1 <- M0 <- run_bridge_sampling(samples_LNR, both_splits = FALSE, cores_for_props = 1)
get_BayesFactor(M1, M0)
```

---

get_data.emc *Get Data*

Description

Extracts data from an emc object

Usage

```
## S3 method for class 'emc'
get_data(emc)

get_data(emc)
```

Arguments

emc	an emc object

Details

emc adds columns and rows to a dataframe in order to facilitate efficient likelihood calculations. This function will return the data as provided originally.

Value

A dataframe of the original data

Examples

```
get_data(samples_LNR)
```

---

get_design.emc.prior *Get Design*

Description

Extracts design from an emc object

Usage

```
## S3 method for class 'emc.prior'
get_design(x)

## S3 method for class 'emc'
get_design(x)

get_design(x)
```

Arguments

x	an emc or emc.prior object

Value

A design with class emc.design

Examples

```
get_design(samples_LNR)
```

get_pars *Filter/Manipulate Parameters from emc Object*

Description

Underlying function used in most plotting and object handling functions in EMC2. Can for example be used to filter/thin a parameter type (i.e, group-level means mu) and convert to an mcmc.list.

Usage

```
get_pars(
  emc,
  selection = "mu",
  stage = get_last_stage(emc),
  thin = 1,
  filter = 0,
  map = FALSE,
  add_recalculated = FALSE,
  length.out = NULL,
  by_subject = FALSE,
  return_mcmc = TRUE,
  merge_chains = FALSE,
  subject = NULL,
  flatten = FALSE,
  remove_dup = FALSE,
  remove_constants = TRUE,
  use_par = NULL,
  type = NULL,
  true_pars = NULL,
  chain = NULL,
  covariates = NULL
)
```

Arguments

emc	an emc object.
selection	A Character string. Indicates which parameter type to select (e.g., alpha, mu, sigma2, correlation).
stage	A character string. Indicates from which sampling stage(s) to take the samples from (i.e. preburn, burn, adapt, sample)
thin	An integer. By how much to thin the chains
filter	Integer or numeric vector. If an integer is supplied, iterations up until that integer are removed. If a vector is supplied, the iterations within the range are kept.
map	Boolean. If TRUE parameters will be mapped back to the cells of the experimental design using the design matrices. Otherwise the sampled parameters are returned. Only works for selection = mu or selection = alpha.

add_recalculated
: Boolean. If TRUE will also add recalculated parameters, such as b in the LBA (b = B + A; see ?LBA), or z in the DDM z = Z*A (see ?DDM) only works when map = TRUE

length.out
: Integer. Alternatively to thinning, you can also select a desired length of the MCMC chains, which will be thinned appropriately.

by_subject
: Boolean. If TRUE for selections that include subject parameters (e.g. alpha), plot/stats are organized by subject, otherwise by parameter.

return_mcmc
: Boolean. If TRUE returns an mcmc.list object, otherwise a matrix/array with the parameter type.

merge_chains
: Boolean. If TRUE returns parameter type merged across chains.

subject
: Integer (vector) or character (vector). If an integer will select the 'x'th subject(s), if a character it should match subject names in the data which will be selected.

flatten
: Boolean. If FALSE for 3-dimensional samples (e.g., correlations: n-pars x n-pars x iterations). organizes by the dimension containing parameter names, otherwise collapses names across the first and second dimension. Does not apply for selection = "alpha"

remove_dup
: Boolean. If TRUE removes duplicate values from the samples. Automatically set to TRUE if flatten = TRUE

remove_constants
: Boolean. If TRUE removes constant values from the samples (e.g. 0s in the covariance matrix).

use_par
: Character (vector). If specified, only these parameters are returned. Should match the parameter names (i.e. these are collapsed when flatten = TRUE and use_par should also be collapsed names).

type
: Character indicating the group-level model selected. Only necessary if sampler isn't specified.

true_pars
: Set of true_parameters can be specified to apply flatten or use_par on a set of true parameters

chain
: Integer. Which of the chain(s) to return

covariates
: Only needed with plot for priors and covariates in the design

Value

An mcmc.list object of the selected parameter types with the specified manipulations

Examples

```
# E.g. get the group-level mean parameters mapped back to the design
get_pars(samples_LNR, stage = "sample", map = TRUE, selection = "mu")

# Or return the flattened correlation, with 10 iterations per chain
get_pars(samples_LNR, stage = "sample", selection = "correlation", flatten = TRUE, length.out = 10)
```

get_prior.emc *Get Prior*

Description

Extracts prior from an emc object

Usage

```
## S3 method for class 'emc'
get_prior(emc)

get_prior(emc)
```

Arguments

emc	an emc object

Value

A prior with class emc.prior

Examples

```
get_prior(samples_LNR)
```

hypothesis.emc *Within-Model Hypothesis Testing*

Description

Approximates the Bayes factor for parameter effects using the savage-dickey ratio.

Usage

```
## S3 method for class 'emc'
hypothesis(
  emc,
  parameter = NULL,
  H0 = 0,
  fun = NULL,
  selection = "mu",
  do_plot = TRUE,
  use_prior_lim = TRUE,
  N = 10000,
  prior_args = list(),
```

```
  ...
)

hypothesis(emc, ...)
```

Arguments

emc	An emc object
parameter	A string. A parameter which you want to compare to H0. Will not be used if a FUN is specified.
H0	An integer. The H0 value which you want to compare to
fun	A function. Specifies an operation to be performed on the sampled or mapped parameters.
selection	A Character string. Indicates which parameter type to use (e.g., alpha, mu, sigma2, correlation).
do_plot	Boolean. If FALSE will omit the prior-posterior plot and only return the savage-dickey ratio.
use_prior_lim	Boolean. If TRUE will use xlimits based on prior density, otherwise based on posterior density.
N	Integer. How many prior samples to draw
prior_args	A list. Optional additional arguments to be passed to plot.default for the plotting of the prior density (see par())
...	Optional arguments that can be passed to get_pars, density, or plot.default (see par())

Details

Note this is different to the computation of the marginal deviance in compare since it only considers the group level effect and not the whole model (i.e. subject-level parameters). For details see: Wagenmakers, Lodewyckx, Kuriyal, & Grasman (2010).

Value

The Bayes factor for the hypothesis against H0.

Examples

```
# Here the emc object has an effect parameter (e.g. m),
# that maps onto a certain hypothesis.
# The hypothesis here is that m is different from zero.
# We can test whether there's a group-level effect on m:
hypothesis(samples_LNR, parameter = "m")
# Alternatively we can also test whether two parameters differ from each other
mdiff <- function(p)diff(p[c("m","m_lMd")])
hypothesis(samples_LNR,fun=mdiff)
```

`init_chains` *Initialize Chains*

Description

Adds a set of start points to each chain. These start points are sampled from a user-defined multivariate normal across subjects.

Usage

```
init_chains(
  emc,
  start_mu = NULL,
  start_var = NULL,
  particles = 1000,
  cores_per_chain = 1,
  cores_for_chains = length(emc)
)
```

Arguments

`emc`	An emc object made by `make_emc()`
`start_mu`	A vector. Mean of multivariate normal used in proposal distribution
`start_var`	A matrix. Variance covariance matrix of multivariate normal used in proposal distribution. Smaller values will lead to less deviation around the mean.
`particles`	An integer. Number of starting values
`cores_per_chain`	An integer. How many cores to use per chain. Parallelizes across participant calculations.
`cores_for_chains`	An integer. How many cores to use to parallelize across chains. Default is the number of chains.

Value

An emc object

Examples

```
# Make a design and an emc object
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1),
                           constants=c(s=log(1)))

DDMaE <- make_emc(forstmann, design_DDMaE)
# set up our mean starting points (same used across subjects).
mu <- c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
```

```
       t0=log(.2))
# Small variances to simulate start points from a tight range
var <- diag(0.05, length(mu))
# Initialize chains, 4 cores per chain, and parallelizing across our 3 chains as well
# so 4*3 cores used.
DDMaE <- init_chains(DDMaE, start_mu = mu, start_var = var,
                     cores_per_chain = 1, cores_for_chains = 1)
# Afterwards we can just use fit
# DDMaE <- fit(DDMaE, cores_per_chain = 4)
```

LBA *The Linear Ballistic Accumulator model*

Description

Model file to estimate the Linear Ballistic Accumulator (LBA) in EMC2.

Usage

```
LBA()
```

Details

Model files are almost exclusively used in `design()`.

Default values are used for all parameters that are not explicitly listed in the `formula` argument of `design()`.They can also be accessed with `LBA()$p_types`.

Parameter	Transform	Natural scale	Default	Mapping	Interpretation
v	-	[-Inf, Inf]	1		Mean evidence-accumulation rate
A	log	[0, Inf]	log(0)		Between-trial variation (range) in start point
B	log	[0, Inf]	log(1)	$b = B+A$	Distance from *A* to *b* (response threshold)
t0	log	[0, Inf]	log(0)		Non-decision time
sv	log	[0, Inf]	log(1)		Between-trial variation in evidence-accumulation rate

All parameters are estimated on the log scale, except for the drift rate which is estimated on the real line.

Conventionally, `sv` is fixed to 1 to satisfy scaling constraints.

The $b = B + A$ parameterization ensures that the response threshold is always higher than the between trial variation in start point of the drift rate.

Because the LBA is a race model, it has one accumulator per response option. EMC2 automatically constructs a factor representing the accumulators `lR` (i.e., the latent response) with level names taken from the `R` column in the data.

The `lR` factor is mainly used to allow for response bias, analogous to `Z` in the DDM. For example, in the LBA, response thresholds are determined by the *B* parameters, so `B~lR` allows for

different thresholds for the accumulator corresponding to left and right stimuli (e.g., a bias to respond left occurs if the left threshold is less than the right threshold). For race models, the design() argument matchfun can be provided, a function that takes the lR factor (defined in the augmented data (d) in the following function) and returns a logical defining the correct response. In the example below, the match is simply such that the S factor equals the latent response factor: matchfun=function(d)d$S==d$lR. Then matchfun is used to automatically create a latent match (lM) factor with levels FALSE (i.e., the stimulus does not match the accumulator) and TRUE (i.e., the stimulus does match the accumulator). This is added internally and can also be used in model formula, typically for parameters related to the rate of accumulation.

Brown, S. D., & Heathcote, A. (2008). The simplest complete model of choice response time: Linear ballistic accumulation. *Cognitive Psychology, 57*(3), 153-178. https://doi.org/10.1016/j.cogpsych.2007.12.002

Value

A model list with all the necessary functions for EMC2 to sample

Examples

```
# When working with lM it is useful to design  an "average and difference"
# contrast matrix, which for binary responses has a simple canonical from:
ADmat <- matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"d"))
# We also define a match function for lM
matchfun=function(d)d$S==d$lR
# We now construct our design, with v ~ lM and the contrast for lM the ADmat.
design_LBABE <- design(data = forstmann,model=LBA,matchfun=matchfun,
                       formula=list(v~lM,sv~lM,B~E+lR,A~1,t0~1),
                       contrasts=list(v=list(lM=ADmat)),constants=c(sv=log(1)))
# For all parameters that are not defined in the formula, default values are assumed
# (see Table above).
```

LNR *The Log-Normal Race Model*

Description

Model file to estimate the Log-Normal Race Model (LNR) in EMC2.

Usage

```
LNR()
```

Details

Model files are almost exclusively used in design().

Default values are used for all parameters that are not explicitly listed in the formula argument of design().They can also be accessed with LNR()$p_types.

Parameter	Transform	Natural scale	Default	Mapping	Interpretation
m	-	[-Inf, Inf]	1		Scale parameter
s	log	[0, Inf]	log(1)		Shape parameter
t0	log	[0, Inf]	log(0)		Non-decision time

Because the LNR is a race model, it has one accumulator per response option. EMC2 automatically constructs a factor representing the accumulators `lR` (i.e., the latent response) with level names taken from the `R` column in the data.

In `design()`, `matchfun` can be used to automatically create a latent match (`lM`) factor with levels `FALSE` (i.e., the stimulus does not match the accumulator) and `TRUE` (i.e., the stimulus does match the accumulator). This is added internally and can also be used in the model formula, typically for parameters related to the rate of accumulation (see the example below).

Rouder, J. N., Province, J. M., Morey, R. D., Gomez, P., & Heathcote, A. (2015). The lognormal race: A cognitive-process model of choice and latency with desirable psychometric properties. *Psychometrika, 80*, 491-513. https://doi.org/10.1007/s11336-013-9396-3

Value

A model list with all the necessary functions for EMC2 to sample

Examples

```
# When working with lM it is useful to design  an "average and difference"
# contrast matrix, which for binary responses has a simple canonical from:
ADmat <- matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"d"))
# We also define a match function for lM
matchfun=function(d)d$S==d$lR
# We now construct our design, with v ~ lM and the contrast for lM the ADmat.
design_LNRmE <- design(data = forstmann,model=LNR,matchfun=matchfun,
                       formula=list(m~lM + E,s~1,t0~1),
                       contrasts=list(m=list(lM=ADmat)))
# For all parameters that are not defined in the formula, default values are assumed
# (see Table above).
```

`make_data` *Simulate Data*

Description

Simulates data based on a model design and a parameter vector (`p_vector`) by one of two methods:

1. Creating a fully crossed and balanced design specified by the design, with number of trials per cell specified by the `n_trials` argument
2. Using the design of a data frame supplied, which allows creation of unbalanced and other irregular designs, and replacing previous data with simulated data

Usage

```
make_data(
  parameters,
  design = NULL,
  n_trials = NULL,
  data = NULL,
  expand = 1,
  mapped_p = FALSE,
  hyper = FALSE,
  ...
)
```

Arguments

parameters	parameter vector used to simulate data. Can also be a matrix with one row per subject (with corresponding row names) or an emc object with sampled parameters (in which case posterior medians of alpha are used to simulate data)
design	Design list created by design()
n_trials	Integer. If data is not supplied, number of trials to create per design cell
data	Data frame. If supplied, the factors are taken from the data. Determines the number of trials per level of the design factors and can thus allow for unbalanced designs
expand	Integer. Replicates the data (if supplied) expand times to increase number of trials per cell.
mapped_p	If TRUE instead returns a data frame with one row per design cell and columns for each parameter specifying how they are mapped to the design cells.
hyper	If TRUE the supplied parameters must be a set of samples, from which the group-level will be used to generate subject level parameters. See also make_random_effects to generate subject-level parameters from a hyper distribution.
...	Additional optional arguments

Details

To create data for multiple subjects see ?make_random_effects().

Value

A data frame with simulated data

Examples

```
# First create a design
design_DDMaE <- design(factors = list(S = c("left", "right"),
                                      E = c("SPD", "ACC"),
                                      subjects = 1:30),
                       Rlevels = c("left", "right"), model = DDM,
                       formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
```

```
                            constants=c(s=log(1)))
# Then create a p_vector:
parameters <- c(v_Sleft=-2,v_Sright=2,a=log(1),a_EACC=log(2), t0=log(.2),
              Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))

# Now we can simulate data
data <- make_data(parameters, design_DDMaE, n_trials = 30)

# We can also simulate data based on a specific dataset
design_DDMaE <- design(data = forstmann,model=DDM,
                            formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                            constants=c(s=log(1)))
parameters <- c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
              t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))

data <- make_data(parameters, design_DDMaE, data = forstmann)
```

---

make_emc *Make an emc Object*

Description

Creates an emc object by combining the data, prior, and model specification into a emc object that is needed in `fit()`.

Usage

```
make_emc(
  data,
  design,
  model = NULL,
  type = "standard",
  n_chains = 3,
  compress = TRUE,
  rt_resolution = 0.02,
  prior_list = NULL,
  par_groups = NULL,
  ...
)
```

Arguments

`data`	A data frame, or a list of data frames. Needs to have the variable `subjects` as participant identifier.
`design`	A list with a pre-specified design, the output of `design()`.
`model`	A model list. If none is supplied, the model specified in `design()` is used.
`type`	A string indicating whether to run a `standard` group-level, `blocked`, `diagonal`, `factor`, or `single` (i.e., non-hierarchical) model.

n_chains	An integer. Specifies the number of mcmc chains to be run (has to be more than 1 to compute rhat).
compress	A Boolean, if TRUE (i.e., the default), the data is compressed to speed up likelihood calculations.
rt_resolution	A double. Used for compression, response times will be binned based on this resolution.
prior_list	A named list containing the prior. Default prior created if NULL. For the default priors, see ?get_prior_{type}.
par_groups	A vector. Only to be specified with type blocked, e.g., c(1,1,1,2,2) means the covariances of the first three and of the last two parameters are estimated as two separate blocks.
...	Additional, optional arguments.

Value

An uninitialized emc object

Examples

```
dat <- forstmann

# function that takes the lR factor (named diff in the following function) and
# returns a logical defining the correct response for each stimulus. In this
# case the match is simply such that the S factor equals the latent response factor.
matchfun <- function(d)d$S==d$lR

# design an "average and difference" contrast matrix
ADmat <- matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"diff"))

# specify design
design_LBABE <- design(data = dat,model=LBA,matchfun=matchfun,
formula=list(v~lM,sv~lM,B~E+lR,A~1,t0~1),
contrasts=list(v=list(lM=ADmat)),constants=c(sv=log(1)))

# specify priors
pmean <- c(v=1,v_lMdiff=1,sv_lMTRUE=log(.5), B=log(.5),B_Eneutral=log(1.5),
           B_Eaccuracy=log(2),B_lRright=0, A=log(0.25),t0=log(.2))
psd <- c(v=1,v_lMdiff=0.5,sv_lMTRUE=.5,
         B=0.3,B_Eneutral=0.3,B_Eaccuracy=0.3,B_lRright=0.3,A=0.4,t0=.5)
prior_LBABE <- prior(design_LBABE, type = 'standard',pmean=pmean,psd=psd)

# create emc object
LBABE <- make_emc(dat,design_LBABE,type="standard",  prior=prior_LBABE)
```

make_random_effects *Generate Subject-Level Parameters*

Description

Simulates subject-level parameters in the format required by `make_data()`.

Usage

```
make_random_effects(
  design,
  group_means,
  n_subj = NULL,
  variance_proportion = 0.2,
  covariances = NULL
)
```

Arguments

`design`	A design list. The design as specified by `design()`
`group_means`	A numeric vector. The group level means for each parameter, in the same order as `sampled_pars(design)`
`n_subj`	An integer. The number of subjects to generate parameters for. If `NULL` will be inferred from design
`variance_proportion`	A double. Optional. If `covariances` are not specified, the variances will be created by multiplying the means by this number. The covariances will be 0.
`covariances`	A covariance matrix. Optional. Specify the intended covariance matrix.

Value

A matrix of subject-level parameters.

Examples

```
# First create a design
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# Then create a group-level means vector:
group_means =c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
               t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
# Now we can create subject-level parameters
subj_pars <- make_random_effects(design_DDMaE, group_means, n_subj = 19)

# We can also define a covariance matrix to simulate from
subj_pars <- make_random_effects(design_DDMaE, group_means, n_subj = 19,
```

```
              covariances = diag(.1, length(group_means)))

# The subject level parameters can be used to generate data
make_data(subj_pars, design_DDMaE, n_trials = 10)
```

---

mapped_pars *Parameter Mapping Back to the Design Factors*

Description

Maps parameters of the cognitive model back to the experimental design. If p_vector is left unspecified will print a textual description of the mapping. Otherwise the p_vector can be created using `sampled_pars()`. The returned matrix shows whether/how parameters differ across the experimental factors.

Usage

```
mapped_pars(
  x,
  p_vector = NULL,
  model = NULL,
  digits = 3,
  remove_subjects = TRUE,
  covariates = NULL,
  ...
)

## S3 method for class 'emc.design'
mapped_pars(
  x,
  p_vector = NULL,
  model = NULL,
  digits = 3,
  remove_subjects = TRUE,
  covariates = NULL,
  ...
)

## S3 method for class 'emc.prior'
mapped_pars(
  x,
  p_vector = NULL,
  model = NULL,
  digits = 3,
  remove_subjects = TRUE,
  covariates = NULL,
  ...
```

```
)

## S3 method for class 'emc'
mapped_pars(
  x,
  p_vector = NULL,
  model = NULL,
  digits = 3,
  remove_subjects = TRUE,
  covariates = NULL,
  ...
)
```

Arguments

x	an emc, emc.prior or emc.design object
p_vector	Optional. Specify parameter vector to get numeric mappings. Must be in the form of sampled_pars(design)
model	Optional model type (if not already specified in design)
digits	Integer. Will round the output parameter values to this many decimals
remove_subjects	Boolean. Whether to include subjects as a factor in the design
covariates	Covariates specified in the design can be included here.
...	optional arguments

Value

Matrix with a column for each factor in the design and for each model parameter type (p_type).

Examples

```
# First define a design:
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
mapped_pars(design_DDMaE)
# Then create a p_vector:
p_vector=c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
          t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
# This will map the parameters of the p_vector back to the design
mapped_pars(design_DDMaE, p_vector)
```

merge_chains *Merge Samples*

Description

Merges samples from all chains as one unlisted object.

Usage

```
merge_chains(emc)
```

Arguments

emc	An emc object, commonly the output of `fit()`

Details

Note that all sampling stages are included in the merged output, including iterations from the `preburn`, `burn`, and `adapt` stages. `merge_chains(emc)$samples$stage` shows the corresponding sampling stages.

Value

An unlisted emc object with all chains merged

model_averaging *Model Averaging*

Description

Computes model weights and a Bayes factor by comparing two groups of models based on their Information Criterion (IC) values. The function works with either numeric vectors or data frames containing multiple IC measures (e.g., MD, BPIC, DIC).

Usage

```
model_averaging(IC_for, IC_against)
```

Arguments

IC_for	A numeric vector or the output of `compare`
IC_against	A numeric vector or the output of `compare`

Details

When provided with numeric vectors, it computes the weights for the two groups by first converting the IC values into relative weights and then normalizing them. When provided with a data frame, it assumes that the data frame is the output of a call to `compare` and applies averaging to each IC metric

Value

A `data.frame` with the following columns:

`wFor` The aggregated weight of the models in favor.

`wAgainst` The aggregated weight of the models against.

`Factor` The Bayes factor (ratio of `wFor` to `wAgainst`).

If `IC_for` is a data frame, a matrix with rows corresponding to each IC measure is returned.

Examples

```
# First set up some example models (normally these would be alternative models)
samples_LNR2 <- subset(samples_LNR, length.out = 45)
samples_LNR3 <- subset(samples_LNR, length.out = 40)
samples_LNR4 <- subset(samples_LNR, length.out = 35)

# Run compare on them, BayesFactor = F is set for speed.
ICs <- compare(list(S1 = samples_LNR, S2 = samples_LNR2,
                    S3 = samples_LNR3, S4 = samples_LNR4), BayesFactor = FALSE)

# Model averaging can either be done with a vector of ICs:
model_averaging(ICs$BPIC[1:2], ICs$BPIC[2:4])

# Or the output of compare:
model_averaging(ICs[1:2,], ICs[3:4,])
```

---

pairs_posterior *Plot Within-Chain Correlations*

Description

Plots within-chain parameter correlations (upper triangle) and corresponding scatterplots (lower triangle) to visualize parameter sloppiness.

Usage

```
pairs_posterior(
  emc,
  selection = "alpha",
  scale_subjects = TRUE,
```

```
  do_plot = TRUE,
  N = 500,
  ...
)
```

Arguments

emc	An emc object
selection	A Character string. Indicates which parameter type to plot (alpha, mu, variance, covariance, correlation).
scale_subjects	Boolean. To standardize each participant with selection = "alpha", by subtracting the mean and divding by the standard deviation. This ensures the plot has every participant on the same scale.
do_plot	Boolean. Whether to plot the pairs plot, if FALSE, only the correlations are returned.
N	Integer for maximum number of iterations used (defaults to 500). If number of samples in stage or selection exceeds N, a random subset will be taken of size N
...	Optional arguments that can be passed to get_pars

Details

If selection = alpha the parameter chains are concatenated across participants, (after standardizing if scale_subjects = TRUE) and then correlated.

Value

Invisibly returns a matrix with the correlations between the parameters.

Examples

```
# Plot the sloppiness for the individual-level subjects
pairs_posterior(samples_LNR, selection = "alpha")

# We can also choose group-level parameters and subsets of the parameter space
pairs_posterior(samples_LNR, use_par = c("m", "t0"), selection = "sigma2")
```

---

parameters.emc.prior *Return Data Frame of Parameters*

Description

Return Data Frame of Parameters

Usage

```
## S3 method for class 'emc.prior'
parameters(x, selection = "mu", N = 1000, covariates = NULL, ...)

## S3 method for class 'emc'
parameters(x, selection = "mu", N = NULL, resample = FALSE, ...)

parameters(x, ...)
```

Arguments

x	An emc or emc.prior object
selection	String designating parameter type (e.g. mu, sigma2, correlation, alpha)
N	Integer. How many samples to take from the posterior/prior. If NULL will return the full posterior
covariates	For priors, possible covariates in the design
...	Optional arguments that can be passed to get_pars
resample	Boolean. If TRUE will sample N samples from the posterior with replacement

Value

A data frame with one row for each sample (with a subjects column if selection = "alpha" and using draws from the posterior)

Examples

```
# For prior inference:
# First set up a prior
design_DDMaE <- design(data = forstmann,model=DDM,
                       formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                       constants=c(s=log(1)))
# Then set up a prior using make_prior
p_vector=c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
           t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
psd <- c(v_Sleft=1,v_Sright=1,a=.3,a_Eneutral=.3,a_Eaccuracy=.3,
         t0=.4,Z=1,sv=.4,SZ=1)
# Here we left the variance prior at default
prior_DDMaE <- prior(design_DDMaE,mu_mean=p_vector,mu_sd=psd)
# Get our prior samples
parameters(prior_DDMaE, N = 100)
# For posterior inference:
# Get 100 samples of the group-level mean (the default)
parameters(samples_LNR, N = 100)
# or from the individual-level parameters and mapped
parameters(samples_LNR, selection = "alpha", map = TRUE)
```

plot.emc *Plot Function for emc Objects*

Description

Makes trace plots for model parameters.

Usage

```
## S3 method for class 'emc'
plot(
  x,
  stage = "sample",
  selection = c("mu", "sigma2", "alpha"),
  layout = NA,
  ...
)
```

Arguments

x	An object of class emc
stage	A character string indicating the sampling stage to be summarized. Can be preburn, burn, adapt, or sample.
selection	A character vector indicating the parameter group(s). Defaults to mu, sigma2, and alpha.
layout	A vector indicating which layout to use as in par(mfrow = layout). If NA, will automatically generate an appropriate layout.
...	Optional arguments that can be passed to get_pars or plot.default (see par())

Value

A trace/acf plot of the selected MCMC chains

Examples

```
plot(samples_LNR)
# Or trace autocorrelation for the second subject:
plot(samples_LNR, subject = 2, selection = "alpha")

# Can also plot the trace of for example the group-level correlation:
plot(samples_LNR, selection = "correlation", col = c("green", "purple", "orange"), lwd = 2)
```

`plot.emc.design` *Plot method for emc.design objects*

Description

Makes design illustration by plotting simulated data based on the design

Usage

```
## S3 method for class 'emc.design'
plot(
  x,
  p_vector,
  data = NULL,
  factors = NULL,
  plot_factor = NULL,
  n_data_sim = 10,
  functions = NULL,
  ...
)
```

Arguments

`x`	An object of class `emc.design` containing the design to plot
`p_vector`	A named vector of parameter values to use for data generation
`data`	Optional data frame to overlay on the design plot. If NULL, data will be simulated.
`factors`	Character vector. Factors to use for varying parameters in the plot
`plot_factor`	Optional character. Make separate plots for each level of this factor
`n_data_sim`	Integer. If data is NULL, number of simulated datasets to generate for the plot. Default is 10.
`functions`	Optional named list of functions that create additional columns in the data
`...`	Additional arguments passed to `make_design_plot`

Value

No return value, called for side effect of plotting

plot.emc.prior *Plot a prior*

Description

Takes a prior object and plots the selected implied prior

Usage

```
## S3 method for class 'emc.prior'
plot(
  x,
  selection = "mu",
  do_plot = TRUE,
  covariates = NULL,
  layout = NA,
  N = 50000,
  ...
)
```

Arguments

x	An emc_prior element
selection	A Character string. Indicates which parameter type to use (e.g., alpha, mu, sigma2, correlation).
do_plot	Boolean. If FALSE will only return prior samples and omit plotting.
covariates	dataframe/functions as specified by the design
layout	A vector indicating which layout to use as in par(mfrow = layout). If NA, will automatically generate an appropriate layout.
N	Integer. How many prior samples to draw
...	Optional arguments that can be passed to get_pars, histogram, plot.default (see par()), or arguments required for the types of models e.g. n_factors for type = "factor"

Value

An invisible mcmc.list object with prior samples of the selected type

Examples

```
# First define a design for the model
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# Then set up a prior using make_prior
p_vector=c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
```

```
          t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
psd <- c(v_Sleft=1,v_Sright=1,a=.3,a_Eneutral=.3,a_Eaccuracy=.3,
          t0=.4,Z=1,sv=.4,SZ=1)
# Here we left the variance prior at default
prior_DDMaE <- prior(design_DDMaE,mu_mean=p_vector,mu_sd=psd)
# Now we can plot all sorts of (implied) priors
plot(prior_DDMaE, selection = "mu", N = 1e3)
plot(prior_DDMaE, selection = "mu", mapped = FALSE, N=1e3)
# We can also plot the implied prior on the participant level effects.
plot(prior_DDMaE, selection = "alpha", col = "green", N = 1e3)
```

`plot_cdf` *Plot Defective Cumulative Distribution Functions*

Description

Plots panels of cumulative distribution functions (CDFs) for each level of the specified defective factor in the data. The CDFs are *defective*; each factor level's CDF scales only up to that level's proportion. Summed across levels, the maximum is 1. Optionally, posterior and/or prior predictive CDFs can be overlaid.

Usage

```
plot_cdf(
  input,
  post_predict = NULL,
  prior_predict = NULL,
  subject = NULL,
  quants = c(0.025, 0.975),
  functions = NULL,
  factors = NULL,
  defective_factor = "R",
  n_cores = 1,
  n_post = 50,
  layout = NA,
  to_plot = c("data", "posterior", "prior")[1:2],
  use_lim = c("data", "posterior", "prior")[1:2],
  legendpos = c("top", "topright"),
  posterior_args = list(),
  prior_args = list(),
  ...
)
```

Arguments

`input`	Either an `emc` object or a data frame, or a *list* of such objects.
`post_predict`	Optional posterior predictive data (matching columns) or *list* thereof.

prior_predict	Optional prior predictive data (matching columns) or *list* thereof.
subject	Subset the data to a single subject (by index or name).
quants	Numeric vector of credible interval bounds (e.g. c(0.025, 0.975)).
functions	A function (or list of functions) that create new columns in the datasets or predictives
factors	Character vector of factor names to aggregate over; defaults to plotting full data set ungrouped by factors if NULL.
defective_factor	Name of the factor used for the defective CDF (default "R").
n_cores	Number of CPU cores to use if generating predictives from an emc object.
n_post	Number of posterior draws to simulate if needed for predictives.
layout	Numeric vector used in par(mfrow=...); use NA for auto-layout.
to_plot	Character vector: any of "data", "posterior", "prior".
use_lim	Character vector controlling which source(s) define xlim.
legendpos	Character vector controlling the positions of the legends
posterior_args	Optional list of graphical parameters for posterior lines/ribbons.
prior_args	Optional list of graphical parameters for prior lines/ribbons.
...	Other graphical parameters for the real data lines.

Value

Returns NULL invisibly.

Examples

```
# Plot defective CDF for data only
# plot_cdf(forstmann, to_plot = "data")
#
# Plot with posterior predictions
# plot_cdf(samples_LNR, to_plot = c("data","posterior"), n_post=10)
#
# Or a list of multiple emc objects ...
```

---

plot_density *Plot Defective Densities*

Description

Plots panels that contain a set of densities for each level of the specified defective factor in the data. These densities are defective; their areas are relative to the respective proportions of the defective factor levels. Across all levels, the area sums to 1. Optionally, posterior/prior predictive densities can be overlaid.

Usage

```
plot_density(
  input,
  post_predict = NULL,
  prior_predict = NULL,
  subject = NULL,
  quants = c(0.025, 0.975),
  functions = NULL,
  factors = NULL,
  defective_factor = "R",
  n_cores = 1,
  n_post = 50,
  layout = NA,
  to_plot = c("data", "posterior", "prior")[1:2],
  use_lim = c("data", "posterior", "prior")[1:2],
  legendpos = c("topright", "top"),
  posterior_args = list(),
  prior_args = list(),
  ...
)
```

Arguments

input	Either an emc object or a data frame, or a *list* of such objects.
post_predict	Optional posterior predictive data (matching columns) or *list* thereof.
prior_predict	Optional prior predictive data (matching columns) or *list* thereof.
subject	Subset the data to a single subject (by index or name).
quants	Numeric vector of credible interval bounds (e.g. c(0.025, 0.975)).
functions	A function (or list of functions) that create new columns in the datasets or predictives
factors	Character vector of factor names to aggregate over; defaults to plotting full data set ungrouped by factors if NULL.
defective_factor	Name of the factor used for the defective CDF (default "R").
n_cores	Number of CPU cores to use if generating predictives from an emc object.
n_post	Number of posterior draws to simulate if needed for predictives.
layout	Numeric vector used in par(mfrow=...); use NA for auto-layout.
to_plot	Character vector: any of "data", "posterior", "prior".
use_lim	Character vector controlling which source(s) define xlim.
legendpos	Character vector controlling the positions of the legends
posterior_args	Optional list of graphical parameters for posterior lines/ribbons.
prior_args	Optional list of graphical parameters for prior lines/ribbons.
...	Other graphical parameters for the real data lines.

Examples

```
# Plot defective densities for each subject and the factor combination in the design:
plot_density(forstmann)
# or for one subject:
plot_density(forstmann, subject = 1)
# Now collapsing across subjects and using a different defective factor:
plot_density(forstmann, factors = "S", defective_factor = "E")
# Or plot posterior predictives
plot_density(samples_LNR, n_post = 10)
```

---

plot_design.emc.design

Plot Design

Description

Makes design illustration by plotting simulated data based on the design

Usage

```
## S3 method for class 'emc.design'
plot_design(
  x,
  data = NULL,
  factors = NULL,
  plot_factor = NULL,
  n_data_sim = 10,
  p_vector = NULL,
  functions = NULL,
  ...
)

## S3 method for class 'emc.prior'
plot_design(
  x,
  data = NULL,
  factors = NULL,
  plot_factor = NULL,
  n_data_sim = 10,
  p_vector = NULL,
  functions = NULL,
  ...
)

plot_design(
  x,
  data = NULL,
```

```
  factors = NULL,
  plot_factor = NULL,
  n_data_sim = 10,
  p_vector = NULL,
  functions = NULL,
  ...
)

## S3 method for class 'emc'
plot_design(
  x,
  data = NULL,
  factors = NULL,
  plot_factor = NULL,
  n_data_sim = 10,
  p_vector = NULL,
  functions = NULL,
  ...
)
```

Arguments

x	An emc or emc.prior object containing the design to plot
data	Optional data to overlay on the design plot
factors	Factors to use for varying parameters
plot_factor	Optional. Make separate plots for each level of this factor
n_data_sim	If data is provided, number of simulated datasets to generate for the plot. Default is 10.
p_vector	Only needed when x is an emc.design object, which parameters to use for data generation.
functions	A named list of functions that create additional columns in the data.
...	Additional arguments to pass to make_design_plot

Value

No return value. Just plots the design

---

plot_pars *Plots Density for Parameters*

Description

Plots the posterior and prior density for selected parameters of a model. Full range of samples manipulations described in get_pars.

Usage

```
plot_pars(
  emc,
  layout = NA,
  selection = "mu",
  show_chains = FALSE,
  plot_prior = TRUE,
  N = 10000,
  use_prior_lim = !all_subjects,
  lpos = "topright",
  true_pars = NULL,
  all_subjects = FALSE,
  prior_args = list(),
  true_args = list(),
  ...
)
```

Arguments

emc	An emc object
layout	A vector indicating which layout to use as in par(mfrow = layout). If NA, will automatically generate an appropriate layout.
selection	A Character string. Indicates which parameter type to use (e.g., alpha, mu, sigma2, correlation).
show_chains	Boolean (defaults to FALSE) plots a separate density for each chain.
plot_prior	Boolean. If TRUE will overlay prior density in the plot (default in red)
N	Integer. How many prior samples to draw
use_prior_lim	Boolean. If TRUE will use xlimits based on prior density, otherwise based on posterior density.
lpos	Character. Where to plot the contraction statistic.
true_pars	A vector or emc object. Can be used to visualize recovery. If a vector will plot a vertical line for each parameter at the appropriate place. If an emc object will plot the densities of the object as well, assumed to be the data-generating posteriors.
all_subjects	Boolean. Will plot the densities of all (selected) subjects overlaid with the group-level distribution
prior_args	A list. Optional additional arguments to be passed to plot.default for the plotting of the prior density (see par())
true_args	A list. Optional additional arguments to be passed to plot.default for the plotting of the true parameters (see par())
...	Optional arguments that can be passed to get_pars, density, or plot.default (see par())

Value

An invisible return of the contraction statistics for the selected parameter type

Examples

```
# Full range of possibilities described in get_pars
plot_pars(samples_LNR)
# Or plot all subjects
plot_pars(samples_LNR, all_subjects = TRUE, col = 'purple')
# Or plot recovery
true_emc <- samples_LNR # This would normally be the data-generating samples
plot_pars(samples_LNR, true_pars = true_emc, true_args = list(col = 'blue'), adjust = 2)
```

---

plot_relations *Plot Group-Level Relations*

Description

An adjusted version of the `corrplot` package function `corrplot()` tailored to `EMC2` and the plotting of estimated correlations.

Usage

```
plot_relations(
  emc = NULL,
  stage = "sample",
  plot_cred = TRUE,
  plot_means = TRUE,
  only_cred = FALSE,
  nice_names = NULL,
  ...
)
```

Arguments

`emc`	An EMC2 object, commonly the output of `run_emc()`.
`stage`	Character. The stage from which to take the samples, defaults to the sampling stage `sample`.
`plot_cred`	Boolean. Whether to plot the 95 percent credible intervals or not
`plot_means`	Boolean. Whether to plot the means or not
`only_cred`	Boolean. Whether to only plot credible values
`nice_names`	Character string. Alternative names to give the parameters
`...`	Optional additional arguments

Value

No return value, creates a plot of group-level relations

Examples

```
# For a given set of hierarchical model samples we can make a
# correlation matrix plot.
plot_relations(samples_LNR, only_cred = TRUE, plot_cred = TRUE)
# We can also only plot the correlations where the credible interval does not include zero
plot_relations(samples_LNR, plot_means = TRUE, only_cred = TRUE)
```

---

plot_sbc_ecdf *Plot the ECDF Difference in SBC Ranks*

Description

Plots the difference in observed cumulative rank statistics and the expected cumulative distribution of a uniform distribution. The blue shaded areas indicate the 95% credible interval.

Usage

```
plot_sbc_ecdf(ranks, layout = NA)
```

Arguments

ranks	A list of named dataframes of the rank statistic
layout	Optional. A numeric vector specifying the layout using par(mfrow = layout)

Value

No returns

---

plot_sbc_hist *Plot the Histogram of the Observed Rank Statistics of SBC*

Description

Note that this plot is dependent on the number of bins, and a more general visualization is to use plot_sbc_ecdf

Usage

```
plot_sbc_hist(ranks, bins = 10, layout = NA)
```

Arguments

ranks	A list of named dataframes of the rank statistic
bins	An integer specifying the number of bins to use when plotting the histogram
layout	Optional. A numeric vector specifying the layout using par(mfrow = layout)

Value

No returns

`plot_stat` *Plot Statistics on Data*

Description

Plots panels that contain a set of densities for each level of the specified `factor` The densities represent the predicted data across the posterior, the vertical lines represent the real data.

Usage

```
plot_stat(
  input,
  post_predict = NULL,
  prior_predict = NULL,
  stat_fun,
  stat_name = NULL,
  subject = NULL,
  factors = NULL,
  n_cores = 1,
  n_post = 50,
  quants = c(0.025, 0.5, 0.975),
  functions = NULL,
  layout = NA,
  to_plot = c("data", "posterior", "prior")[1:2],
  use_lim = c("data", "posterior", "prior")[1:2],
  legendpos = c("topleft", "top"),
  posterior_args = list(),
  prior_args = list(),
  ...
)
```

Arguments

`input`	Either an `emc` object or a data frame, or a *list* of such objects.
`post_predict`	Optional posterior predictive data (matching columns) or *list* thereof.
`prior_predict`	Optional prior predictive data (matching columns) or *list* thereof.
`stat_fun`	A function that can be applied to the data and returns a single value or a vector of values.
`stat_name`	The name of the calculated quantity
`subject`	Subset the data to a single subject (by index or name).
`factors`	Character vector of factor names to aggregate over; defaults to plotting full data set ungrouped by factors if `NULL`.

n_cores	Number of CPU cores to use if generating predictives from an emc object.
n_post	Number of posterior draws to simulate if needed for predictives.
quants	Numeric vector of credible interval bounds (e.g. c(0.025, 0.975)).
functions	A function (or list of functions) that create new columns in the datasets or predictives
layout	Numeric vector used in par(mfrow=...); use NA for auto-layout.
to_plot	Character vector: any of "data", "posterior", "prior".
use_lim	Character vector controlling which source(s) define xlim.
legendpos	Character vector controlling the positions of the legends
posterior_args	Optional list of graphical parameters for posterior lines/ribbons.
prior_args	Optional list of graphical parameters for prior lines/ribbons.
...	Other graphical parameters for the real data lines.

Value

an invisible data frame with the stat applied to the real data, posterior predictives and/or prior predictives

Examples

```
# For example plot the observed and predicted response accuracy
# Can also apply more sophisticated statistics
drt <- function(data) diff(tapply(data$rt,data[,c("E")],mean))
plot_stat(samples_LNR, stat_fun = drt, n_post = 10, stat_name = "RT diff Speed - A/N")
```

---

predict.emc.prior *Generate Posterior/Prior Predictives*

Description

Simulate n_post data sets using the posterior/prior parameter estimates

Usage

```
## S3 method for class 'emc.prior'
predict(object, data = NULL, n_post = 50, n_cores = 1, n_trials = NULL, ...)

## S3 method for class 'emc'
predict(
  object,
  hyper = FALSE,
  n_post = 50,
  n_cores = 1,
  stat = c("random", "mean", "median")[1],
  ...
)
```

Arguments

object	An emc or emc.prior object from which to generate predictives
data	A data frame needed to exactly match the original design
n_post	Integer. Number of generated datasets
n_cores	Integer. Number of cores across which there should be parallellized
n_trials	An integer. If data isn't provided (although preferred), can generate data based on n_trials per cell of design
...	Optional additional arguments passed to get_pars or make_data
hyper	Boolean. Defaults to FALSE. If TRUE, simulates from the group-level (hyper) parameters instead of the subject-level parameters.
stat	Character. Can be mean, median or random (i.e., the default). Will take either random samples from the chain(s) or use the mean or median of the parameter estimates.

Value

A list of simulated data sets of length n_post

Examples

```
# based on an emc object ran by fit() we can generate posterior predictives
predict(samples_LNR, n_cores = 1, n_post = 10)
```

---

prior *Specify Priors for the Chosen Model*

Description

These values are entered manually by default but can be recycled from another prior (given in the update argument).

Usage

```
prior(
  design,
  type = NULL,
  update = NULL,
  do_ask = NULL,
  fill_default = TRUE,
  ...
)
```

Arguments

design	Design list for which a prior is constructed, typically the output of design()
type	Character. What type of group-level model you plan on using i.e. diagonal
update	Prior list from which to copy values
do_ask	Character. For which parameter types or hyperparameters to ask for prior specification, i.e. Sigma, mu or loadings for factor models, but theta_mu_mean or A also works.
fill_default	Boolean, If TRUE will fill all non-specified parameters, and parameters outside of do_ask, to default values
...	Either values to prefill, i.e. theta_mu_mean = c(1:6), or additional arguments such as n_factors = 2

Details

Where a value is not supplied, the user is prompted to enter numeric values (or functions that evaluate to numbers).

To get the prior help use prior_help(type). With type e.g. 'diagonal'.

Value

A prior list object

Examples

```
# First define a design for the model
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# Then set up a prior using prior
p_vector=c(v_Sleft=-2,v_Sright=2,a=log(1),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
                     t0=log(.2),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
psd <- c(v_Sleft=1,v_Sright=1,a=.3,a_Eneutral=.3,a_Eaccuracy=.3,
                     t0=.4,Z=1,sv=.4,SZ=1)
# Here we left the variance prior at default
prior_DDMaE <- prior(design_DDMaE,mu_mean=p_vector,mu_sd=psd)
# Also add a group-level variance prior:
pscale <- c(v_Sleft=.6,v_Sright=.6,a=.3,a_Eneutral=.3,a_Eaccuracy=.3,
                             t0=.2,Z=.5,sv=.4,SZ=.3)
df <- .4
prior_DDMaE <- prior(design_DDMaE,mu_mean=p_vector,mu_sd=psd, A = pscale, df = df)
# If we specify a new design
design_DDMat0E <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~E, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# We can easily update the prior
prior_DDMat0E <- prior(design_DDMat0E, update = prior_DDMaE)
```

prior_help *Prior Specification Information*

Description

Prints information associated with the prior for certain 'type'

Usage

```
prior_help(type)
```

Arguments

type	A character string indicating which 'type' of model to run (e.g. 'standard' or 'single')

Value

Invisible return with a list of all the information that is also printed

Examples

```
prior_help('diagonal')
```

profile_plot *Likelihood Profile Plots*

Description

Creates likelihood profile plots from a design and the experimental data by varying one model parameter while holding all others constant.

Usage

```
profile_plot(
  data,
  design,
  p_vector,
  range = 0.5,
  layout = NA,
  p_min = NULL,
  p_max = NULL,
  use_par = NULL,
  n_point = 100,
  n_cores = 1,
  round = 3,
```

```
  true_args = list(),
  ...
)
```

Arguments

data	A dataframe. Experimental data used, needed for the design mapping
design	A design list. Created using design.
p_vector	Named vector of parameter values (typically created with sampled_pars(design))
range	Numeric. The max and min will be p_vector + range/2 and p_vector - range/2, unless specified in p_min or p_max.
layout	A vector indicating which layout to use as in par(mfrow = layout). If NA, will automatically generate an appropriate layout.
p_min	Named vector. If specified will instead use these values for minimum range of the selected parameters.
p_max	Named vector. If specified will instead use these values for maximum range of the selected parameters.
use_par	Character vector. If specified will only plot the profiles for the specified parameters.
n_point	Integer. Number of evenly spaced points at which to calculate likelihood
n_cores	Number of likelihood points evenly spaced between the minimum and maximum likelihood range.
round	Integer. To how many digits will the output be rounded.
true_args	A list. Optional additional arguments that can be passed to plot.default for the plotting of the true vertical line.
...	Optional additional arguments that can be passed to plot.default.

Value

Vector with highest likelihood point, input and mismatch between true and highest point

Examples

```
# First create a design
design_DDMaE <- design(data = forstmann,model=DDM,
                       formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                       constants=c(s=log(1)))
# Then create a p_vector:
p_vector=c(v_Sleft=-2,v_Sright=2,a=log(.95),a_Eneutral=log(1.5),a_Eaccuracy=log(2),
          t0=log(.25),Z=qnorm(.5),sv=log(.5),SZ=qnorm(.5))
# Make a profile plot for some parameters. Specifying a custom range for t0.
profile_plot(p_vector = p_vector, p_min = c(t0 = -1.35),
             p_max = c(t0 = -1.45), use_par = c("a", "t0", "SZ"),
             data = forstmann, design = design_DDMaE, n_point = 10)
```

RDM *The Racing Diffusion Model*

Description

Model file to estimate the Racing Diffusion Model (RDM), also known as the Racing Wald Model.

Usage

```
RDM()
```

Details

Model files are almost exclusively used in `design()`.

Default values are used for all parameters that are not explicitly listed in the `formula` argument of `design()`.They can also be accessed with `RDM()$p_types`.

Parameter	Transform	Natural scale	Default	Mapping	Interpretation
v	log	[0, Inf]	log(1)		Evidence-accumulation rate (drift rate)
A	log	[0, Inf]	log(0)		Between-trial variation (range) in start point
B	log	[0, Inf]	log(1)	$b = B + A$	Distance from *A* to *b* (response threshold)
t0	log	[0, Inf]	log(0)		Non-decision time
sv	log	[0, Inf]	log(1)		Within-trial standard deviation of drift rate

All parameters are estimated on the log scale.

The parameterization $b = B + A$ ensures that the response threshold is always higher than the between trial variation in start point.

Conventionally, `s` is fixed to 1 to satisfy scaling constraints.

Because the RDM is a race model, it has one accumulator per response option. EMC2 automatically constructs a factor representing the accumulators `lR` (i.e., the latent response) with level names taken from the `R` column in the data.

The `lR` factor is mainly used to allow for response bias, analogous to *Z* in the DDM. For example, in the RDM, response thresholds are determined by the *B* parameters, so `B~lR` allows for different thresholds for the accumulator corresponding to "left" and "right" stimuli, for example, (e.g., a bias to respond left occurs if the left threshold is less than the right threshold).

For race models in general, the argument `matchfun` can be provided in `design()`. One needs to supply a function that takes the `lR` factor (defined in the augmented data (d) in the following function) and returns a logical defining the correct response. In the example below, this is simply whether the `S` factor equals the latent response factor: `matchfun=function(d)d$S==d$lR`. Using `matchfun` a latent match factor (`lM`) with levels `FALSE` (i.e., the stimulus does not match the accumulator) and `TRUE` (i.e., the stimulus does match the accumulator). This is added internally and can also be used in model formula, typically for parameters related to the rate of accumulation.

Tillman, G., Van Zandt, T., & Logan, G. D. (2020). Sequential sampling models without random between-trial variability: The racing diffusion model of speeded decision making. *Psychonomic Bulletin & Review, 27*(5), 911-936. https://doi.org/10.3758/s13423-020-01719-6

Value

A list defining the cognitive model

Examples

```
# When working with lM it is useful to design  an "average and difference"
# contrast matrix, which for binary responses has a simple canonical from:
ADmat <- matrix(c(-1/2,1/2),ncol=1,dimnames=list(NULL,"d"))
# We also define a match function for lM
matchfun=function(d)d$S==d$lR
# We now construct our design, with v ~ lM and the contrast for lM the ADmat.
design_RDMBE <- design(data = forstmann,model=RDM,matchfun=matchfun,
                       formula=list(v~lM,s~lM,B~E+lR,A~1,t0~1),
                       contrasts=list(v=list(lM=ADmat)),constants=c(s=log(1)))
# For all parameters that are not defined in the formula, default values are assumed
# (see Table above).
```

---

recovery.emc *Recovery Plots*

Description

Plots recovery of data generating parameters/samples. Full range of samples manipulations described in `get_pars`

Usage

```
## S3 method for class 'emc'
recovery(
  emc,
  true_pars,
  selection = "mu",
  layout = NA,
  do_CI = TRUE,
  correlation = "pearson",
  stat = "rmse",
  digits = 3,
  CI = 0.95,
  ci_plot_args = list(),
  ...
)

recovery(emc, ...)
```

Arguments

emc	An emc object
true_pars	A vector of data-generating parameters or an emc object with data-generating samples
selection	A Character vector. Indicates which parameter types to plot (e.g., alpha, mu, sigma2, correlation).
layout	A vector indicating which layout to use as in par(mfrow = layout). If NA, will automatically generate an appropriate layout.
do_CI	Boolean. If TRUE will also include bars representing the credible intervals
correlation	Character. Which correlation to include in the plot. Options are either pearson or spearman
stat	Character. Which statistic to include in the plot. Options are either rmse or coverage
digits	Integer. How many digits to round the statistic and correlation in the plot to
CI	Numeric. The size of the credible intervals. Default is .95 (95%).
ci_plot_args	A list. Optional additional arguments to be passed to plot.default for the plotting of the credible intervals (see par())
...	Optional arguments that can be passed to get_pars or plot.default (see par())

Value

Invisible list with RMSE, coverage, and Pearson and Spearman correlations.

Examples

```
# Make up some values that resemble posterior samples
# Normally this would be true values that were used to simulate the data
# Make up some values that resemble posterior samples
# Normally this would be true values that were used to simulate the data
pmat <- matrix(rnorm(12, mean = c(-1, -.6, -.4, -1.5), sd = .01), ncol = 4, byrow = TRUE)
# Conventionally this would be created before one makes data with true values
recovery(samples_LNR, pmat, correlation = "pearson", stat = "rmse", selection = "alpha")
# Similarly we can plot recovery of other parameters with a set of true samples
true_samples <- samples_LNR # Normally this would be data-generating samples
recovery(samples_LNR, true_samples, correlation = "pearson", stat = "rmse",
         selection = "correlation", cex = 1.5,
         ci_plot_args = list(lty = 3, length = .2, lwd = 2, col = "brown"))
```

---

run_bridge_sampling *Estimating Marginal Likelihoods Using WARP-III Bridge Sampling*

Description

Uses bridge sampling that matches a proposal distribution to the first three moments of the posterior distribution to get an accurate estimate of the marginal likelihood. The marginal likelihood can be used for computing Bayes factors and posterior model probabilities.

Usage

```
run_bridge_sampling(
  emc,
  stage = "sample",
  filter = NULL,
  repetitions = 1,
  cores_for_props = 4,
  cores_per_prop = 1,
  both_splits = TRUE,
  ...
)
```

Arguments

emc	An emc object with a set of converged samples
stage	A character indicating which stage to use, defaults to sample
filter	An integer or vector. If integer, it will exclude up until that integer. If vector it will include everything in that range.
repetitions	An integer. How many times to repeat the bridge sampling scheme. Can help get an estimate of stability of the estimate.
cores_for_props	Integer. Warp-III evaluates the posterior over 4 different proposal densities. If you have the CPU, 4 cores will do this in parallel, 2 is also already helpful.
cores_per_prop	Integer. Per density we can also parallelize across subjects. Eventual cores will be cores_for_props * cores_per_prop. For efficiency users should prioritize cores_for_props being 4.
both_splits	Boolean. Bridge sampling uses a proposal density and a target density. We can estimate the stability of our samples and therefore MLL estimate, by running 2 bridge sampling iterations The first one uses the first half of the samples as the proposal and the second half as the target, the second run uses the opposite. If this is is set to FALSE, it will only run bridge sampling once and it will instead do an odd-even iterations split to get a more reasonable estimate for just one run.
...	Additional, optional more in-depth hyperparameters

Details

If not enough posterior samples were collected using fit(), bridge sampling can be unstable. It is recommended to run run_bridge_sampling() several times with the repetitions argument and to examine how stable the results are.

It can be difficult to converge bridge sampling for exceptionally large models, because of a large number of subjects (> 100) and/or cognitive model parameters.

For a practical introduction:

Gronau, Q. F., Heathcote, A., & Matzke, D. (2020). Computing Bayes factors for evidence-accumulation models using Warp-III bridge sampling. *Behavior research methods*, 52(2), 918-937. doi.org/10.3758/s13428-019-01290-6

For mathematical background:

Meng, X.-L., & Wong, W. H. (1996). Simulating ratios of normalizing constants via a simple identity: A theoretical exploration. *Statistica Sinica*, 6, 831-860. http://www3.stat.sinica.edu.tw/statistica/j6n4/j6n43/j6n43.htm

Meng, X.-L., & Schilling, S. (2002). Warp bridge sampling. *Journal of Computational and Graphical Statistics*, 11(3), 552-586. doi.org/10.1198/106186002457

Value

A vector of length repetitions which contains the marginal log likelihood estimates per repetition

Examples

```
# After `fit` has converged on a specific model
# We can take those samples and calculate the marginal log-likelihood for them
MLL <- run_bridge_sampling(samples_LNR, cores_for_props = 1, both_splits = FALSE)
# This will run on 2*4 cores (since 4 is the default for ``cores_for_props``)
```

---

run_emc *Custom Function for More Controlled Model Estimation*

Description

Although typically users will rely on `fit`, this function can be used for more fine-tuned specification of estimation needs. The function will throw an error if a stage is skipped, the stages have to be run in order ("preburn", "burn", "adapt", "sample"). More details can be found in the `fit` help files (`?fit`).

Usage

```
run_emc(
  emc,
  stage,
  stop_criteria,
  search_width = 1,
  step_size = 100,
  verbose = FALSE,
  verboseProgress = FALSE,
  fileName = NULL,
  particles = NULL,
  particle_factor = 50,
  cores_per_chain = 1,
  cores_for_chains = length(emc),
  max_tries = 20,
  n_blocks = 1,
  thin_auto = FALSE
)
```

Arguments

emc	An emc object
stage	A string. Indicates which stage is to be run, either preburn, burn, adapt or sample
stop_criteria	A list. Defines the stopping criteria and for which types of parameters these should hold. See ?fit.
search_width	A double. Tunes target acceptance probability of the MCMC process. This fine-tunes the width of the search space to obtain the desired acceptance probability. 1 is the default width, increases lead to broader search.
step_size	An integer. After each step, the stopping requirements as specified by stop_criteria are checked and proposal distributions are updated. Defaults to 100.
verbose	Logical. Whether to print messages between each step with the current status regarding the stop_criteria.
verboseProgress	Logical. Whether to print a progress bar within each step or not. Will print one progress bar for each chain and only if cores_for_chains = 1.
fileName	A string. If specified will autosave emc at this location on every iteration.
particles	An integer. How many particles to use, default is NULL and particle_factor is used instead. If specified will override particle_factor.
particle_factor	An integer. particle_factor multiplied by the square root of the number of sampled parameters determines the number of particles used.
cores_per_chain	An integer. How many cores to use per chain. Parallelizes across participant calculations. Only available on Linux or Mac OS. For Windows, only parallelization across chains (cores_for_chains) is available.
cores_for_chains	An integer. How many cores to use across chains. Defaults to the number of chains. the total number of cores used is equal to cores_per_chain * cores_for_chains.
max_tries	An integer. How many times should it try to meet the finish conditions as specified by stop_criteria? Defaults to 20. max_tries is ignored if the required number of iterations has not been reached yet.
n_blocks	An integer. Number of blocks. Will block the parameter chains such that they are updated in blocks. This can be helpful in extremely tough models with a large number of parameters.
thin_auto	A boolean. If TRUE will automatically thin the MCMC samples, closely matched to the ESS.

Value

An emc object

Examples

```
# First define a design
design_in <- design(data = forstmann,model=DDM,
                            formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                            constants=c(s=log(1)))
# Then make the emc, we've omitted a prior here for brevity so default priors will be used.
emc <- make_emc(forstmann, design_in)

# Now for example we can specify that we only want to run the "preburn" phase
# for MCMC 10 iterations
emc <- run_emc(emc, stage = "preburn", stop_criteria = list(iter = 10), cores_for_chains = 1)
```

---

run_sbc *Simulation-Based Calibration*

Description

Runs SBC for an EMC2 model and associated design. Returns normalized rank (between 0 and 1) and prior samples. For hierarchical models the group-level mean and the (implied) group-level (co-)variance are returned. For non-hierarchical models only the subject-level parameters rank is returned.

Usage

```
run_sbc(
  design_in,
  prior_in,
  replicates = 250,
  trials = 100,
  n_subjects = 30,
  plot_data = FALSE,
  verbose = TRUE,
  fileName = NULL,
  ...
)
```

Arguments

design_in	An emc design list. The design of the model to be used in SBC
prior_in	An emc prior list. The prior for the design to be used in SBC
replicates	Integer. The number of samples to draw from the prior
trials	Integer. The number of trials of the simulated data (per subject)
n_subjects	Integer. Only used for hierarchical models. The number of subjects to be used in data generation of each replicate
plot_data	Boolean. Whether to plot the data simulated (aggregated across subjects)

verbose	Verbose. Whether to print progress related messages
fileName	Character. Highly recommended, saves temporary results to the fileName
...	A list of optional additional arguments that can be passed to fit and make_emc

Value

The ranks and prior samples. For hierarchical models also the prior-generated subject-level parameters.

---

sampled_pars *Get Model Parameters from a Design*

Description

Makes a vector with zeroes, with names and length corresponding to the model parameters of the design.

Usage

```
sampled_pars(
  x,
  model = NULL,
  doMap = TRUE,
  add_da = FALSE,
  all_cells_dm = FALSE
)

## S3 method for class 'emc.design'
sampled_pars(
  x,
  model = NULL,
  doMap = TRUE,
  add_da = FALSE,
  all_cells_dm = FALSE
)

## S3 method for class 'emc.prior'
sampled_pars(
  x,
  model = NULL,
  doMap = TRUE,
  add_da = FALSE,
  all_cells_dm = FALSE
)

## S3 method for class 'emc'
```

```
sampled_pars(
  x,
  model = NULL,
  doMap = TRUE,
  add_da = FALSE,
  all_cells_dm = FALSE
)
```

Arguments

x	an emc.design object made with design() or an emc object.
model	a model list. Defaults to the model specified in the design list.
doMap	logical. If TRUE will also include an attribute map with the design matrices that perform the mapping back to the design
add_da	Boolean. Whether to include the relevant data columns in the map attribute
all_cells_dm	Boolean. Whether to include all levels of a factor in the mapping attribute, even when one is dropped in the design

Value

Named vector.

Examples

```
# First define a design
design_DDMaE <- design(data = forstmann,model=DDM,
                           formula =list(v~0+S,a~E, t0~1, s~1, Z~1, sv~1, SZ~1),
                           constants=c(s=log(1)))
# Then for this design get which cognitive model parameters are sampled:
sampled_pars(design_DDMaE)
```

---

samples_LNR *LNR Model of Forstmann Data (First 3 Subjects)*

Description

An emc object with a limited number of samples and subjects of the Forstmann dataset. The object is a nested list of lenght three, each list containing the MCMC samples of the respective chain. The MCMC samples are stored in the samples element.

Usage

```
samples_LNR
```

Format

An emc object. An emc object is a list with a specific structure and elements, as outlined below.

data A list of dataframes, one for each subject included

par_names A character vector containing the model parameter names

n_pars The number of parameters in the model

n_subjects The number of unique subject ID's in the data

model A list containing the model functions

nuisance A logical vector indicating which parameters are nuisance parameters

subjects A vector containing the unique subject ID's

type The type of model e.g., "standard" or "diagonal"

prior A list that holds the prior for `theta_mu` (the model parameters). Contains the mean (`theta_mu_mean`), covariance matrix (`theta_mu_var`), degrees of freedom (`v`), and scale (`A`) and inverse covariance matrix (`theta_mu_invar`)

samples A list with defined structure containing the samples, see the Samples Element section for more detail

sampler_nuis A sampler list for nuisance parameters (in this case there are none), similarly structured to the overall samples list of one of the MCMC chains.

Samples Element

The samples element of a emc object contains the different types of samples estimated by EMC2. These include the three main types of samples `theta_mu`, `theta_var` and `alpha` as well as a number of other items which are detailed here.

theta_mu samples used for estimating the model parameters (group level), an array of size (n_pars x n_samples)

theta_var samples used for estimating the parameter covariance matrix, an array of size (n_pars x n_pars x n_samples)

alpha samples used for estimating the subject random effects, an array of size (n_pars x n_subjects x n_samples)

stage A vector containing what PMwG stage each sample was drawn in

subj_ll The winning particles log-likelihood for each subject and sample

a_half Mixing weights used during the Gibbs step when creating a new sample for the covariance matrix

last_theta_var_inv The inverse of the last samples covariance matrix

idx The index of the last sample drawn

Source

https://www.pnas.org/doi/10.1073/pnas.0805903105

subset.emc *Shorten an emc Object*

Description

Shorten an emc Object

Usage

```
## S3 method for class 'emc'
subset(
  x,
  stage = "sample",
  filter = NULL,
  thin = 1,
  keep_stages = FALSE,
  length.out = NULL,
  ...
)
```

Arguments

x	an emc object
stage	A character string. Indicates from which sampling stage(s) to take the samples from (i.e. preburn, burn, adapt, sample)
filter	Integer or numeric vector. If an integer is supplied, iterations up until that integer are removed. If a vector is supplied, the iterations within the range are kept.
thin	An integer. By how much to thin the chains
keep_stages	Boolean. If TRUE, will not remove samples from unselected stages.
length.out	Integer. Alternatively to thinning, you can also select a desired length of the MCMC chains, which will be thinned appropriately.
...	additional optional arguments

Value

A shortened emc object

Examples

```
subset(samples_LNR, length.out = 10)
```

summary.emc *Summary Statistics for emc Objects*

Description

Computes quantiles, Rhat and ESS for selected model parameters.

Usage

```
## S3 method for class 'emc'
summary(
  object,
  selection = c("mu", "sigma2", "alpha"),
  probs = c(0.025, 0.5, 0.975),
  digits = 3,
  ...
)
```

Arguments

object	An object of class emc
selection	A character string indicating the parameter type Defaults to mu, sigma2, and alpha. See below for more information.
probs	The quantiles to be computed. Defaults to the the 2.5%, 50% and 97.5% quantiles.
digits	An integer specifying rounding of output.
...	Optional arguments that can be passed to get_pars

Details

Note that if selection = alpha and by_subject = TRUE (default) is used, summary statistics are computed at the individual level. to the console but summary statistics for all subjects are returned by the function.

Value

A list of summary output.

summary.emc.design *Summary method for emc.design objects*

Description

Prints a summary of the design object, including sampled parameters and design matrices. For continuous covariates just prints one row, instead of all covariates.

Usage

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

Arguments

object	An object of class emc.design containing the design to summarize
...	Additional arguments (not used)

Value

Invisibly returns the design matrices

summary.emc.prior *Summary method for emc.prior objects*

Description

Prints a summary of the prior specification, including descriptions of the prior types and their associated hyperparameters.

Usage

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

Arguments

object	An object of class 'emc.prior' containing prior specifications
...	Additional arguments passed to other methods (not currently used)

Value

Invisibly returns NULL. Called for its side effect of printing the summary.

See Also

prior for creating prior objects

Examples

```
# Take a prior object
prior <- get_prior(samples_LNR)
summary(prior)
```

---

update2version *Update EMC Objects to the Current Version*

Description

This function updates EMC objects created with older versions of the package to be compatible with the current version.

Usage

```
update2version(emc)
```

Arguments

emc	An EMC object to update

Value

An updated EMC object compatible with the current version

Examples

```
# Update the model to current version
updated_model <- update2version(samples_LNR)
```

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