

Package: projpred (via r-universe)

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Title Projection Predictive Feature Selection

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Description Performs projection predictive feature selection for generalized linear models (Pironen, Paasiniemi, and Vehtari, 2020, <[doi:10.1214/20-EJS1711](https://doi.org/10.1214/20-EJS1711)>) with or without multilevel or additive terms (Catalina, Bürkner, and Vehtari, 2022, <<https://proceedings.mlr.press/v151/catalina22a.html>>), for some ordinal and nominal regression models (Weber and Vehtari, 2023, <[arXiv:2301.01660](https://arxiv.org/abs/2301.01660)>), and for many other regression models (using the latent projection by Catalina, Bürkner, and Vehtari, 2021, <[arXiv:2109.04702](https://arxiv.org/abs/2109.04702)>, which can also be applied to most of the former models). The package is compatible with the 'rstanarm' and 'brms' packages, but other reference models can also be used. See the vignettes and the documentation for more information and examples.

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URL <https://mc-stan.org/projpred/>, <https://discourse.mc-stan.org>

BugReports <https://github.com/stan-dev/projpred/issues/>

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Rcpp,

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ordinal,

nnet,
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Suggests ggrepel,

rstanarm,
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iterators,
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rmarkdown,
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projpred-package	<i>Projection predictive feature selection</i>
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Description

The R package **projpred** performs the projection predictive variable (or "feature") selection for various regression models. We recommend to read the README file (available with enhanced formatting [online](#)) and the main vignette (topic = "projpred", but also available [online](#)) before continuing here.

Throughout the whole package documentation, we use the term "submodel" for all kinds of candidate models onto which the reference model is projected. For custom reference models, the candidate models don't need to be actual *submodels* of the reference model, but in any case (even for custom reference models), the candidate models are always actual *submodels* of the full [formula](#) used by the search procedure. In this regard, it is correct to speak of *submodels*, even in case of a custom reference model.

The following model type abbreviations will be used at multiple places throughout the documentation: GLM (generalized linear model), GLMM (generalized linear multilevel—or "mixed"—model), GAM (generalized additive model), and GAMM (generalized additive multilevel—or "mixed"—model). Note that the term "generalized" includes the Gaussian family as well.

For the projection of the reference model onto a submodel, **projpred** currently relies on the following functions (in other words, these are the workhorse functions used by the default divergence minimizers):

- Submodel without multilevel or additive terms:
 - For the traditional (or latent) projection (or the augmented-data projection in case of the `binomial()` or `brms::bernoulli()` family): An internal C++ function which basically serves the same purpose as `lm()` for the `gaussian()` family and `glm()` for all other families.
 - For the augmented-data projection: `MASS::polr()` for the `brms::cumulative()` family or `rstanarm::stan_polr()` fits, `nnet::multinom()` for the `brms::categorical()` family.
- Submodel with multilevel but no additive terms:
 - For the traditional (or latent) projection (or the augmented-data projection in case of the `binomial()` or `brms::bernoulli()` family): `lme4::lmer()` for the `gaussian()` family, `lme4::glmer()` for all other families.
 - For the augmented-data projection: `ordinal::clmm()` for the `brms::cumulative()` family, `mclogit::mblogit()` for the `brms::categorical()` family.
- Submodel without multilevel but additive terms: `mgcv::gam()`.
- Submodel with multilevel and additive terms: `gamm4::gamm4()`.

Setting the global option `projpred.extra_verbosity` to `TRUE` will print out which submodel **projpred** is currently projecting onto as well as (if `method = "forward"` and `verbose = TRUE` in `varsel()` or `cv_varsel()`) which submodel has been selected at those steps of the forward search for which a percentage (of the maximum submodel size that the search is run up to) is printed. In general, however, we cannot recommend setting this global option to `TRUE` for `cv_varsel()` with `validate_search = TRUE` (simply due to the amount of information that will be printed, but also due to the progress bar which will not work anymore as intended).

The projection of the reference model onto a submodel can be run on multiple CPU cores in parallel (across the projected draws). This is powered by the **foreach** package. Thus, any parallel (or sequential) backend compatible with **foreach** can be used, e.g., the backends from packages **doParallel**, **doMPI**, or **doFuture**. Using the global option `projpred.prll_prj_trigger`, the number of projected draws below which no parallelization is applied (even if a parallel backend is registered) can be modified. Such a "trigger" threshold exists because of the computational overhead of a parallelization which makes parallelization only useful for a sufficiently large number of projected draws. By default, parallelization is turned off, which can also be achieved by supplying `Inf` (or `NULL`) to option `projpred.prll_prj_trigger`. Note that we cannot recommend parallelizing the projection on Windows because in our experience, the parallelization overhead is larger there, causing a parallel run to take longer than a sequential run. Also note that the parallelization works well for GLMs, but for all other models, the fitted model objects are quite big, which—when running in parallel—may lead to excessive memory usage which in turn may crash the R session. Thus, we currently cannot recommend the parallelization for models other than GLMs.

In case of multilevel models, **projpred** offers two global options for "integrating out" group-level effects: `projpred.mlvl_pred_new` and `projpred.mlvl_proj_ref_new`. When setting `projpred.mlvl_pred_new` to `TRUE` (default is `FALSE`), then at *prediction* time, **projpred** will treat group levels existing in the training data as *new* group levels, implying that their group-level effects are drawn randomly from a (multivariate) Gaussian distribution. This concerns both, the reference model and the (i.e., any) submodel. Furthermore, setting `projpred.mlvl_pred_new` to `TRUE` causes `as.matrix.projection()` to omit the projected group-level effects (for the group levels from the original dataset). When setting `projpred.mlvl_proj_ref_new` to `TRUE` (default is `FALSE`), then at *projection* time, the reference model's fitted values (that the submodels fit to) will be computed by treating the group levels

from the original dataset as *new* group levels, implying that their group-level effects will be drawn randomly from a (multivariate) Gaussian distribution (as long as the reference model is a multilevel model, which—for custom reference models—does not need to be the case). This also affects the latent response values for a latent projection correspondingly. Setting `projpred.mlv1_pred_new` to TRUE makes sense, e.g., when the prediction task is such that any group level will be treated as a new one. Typically, setting `projpred.mlv1_proj_ref_new` to TRUE only makes sense when `projpred.mlv1_pred_new` is already set to TRUE. In that case, the default of FALSE for `projpred.mlv1_proj_ref_new` ensures that at projection time, the submodels fit to the best possible fitted values from the reference model, and setting `projpred.mlv1_proj_ref_new` to TRUE would make sense if the group-level effects should be integrated out completely.

Functions

`init_refmodel()`, `get_refmodel()` For setting up an object containing information about the reference model, the submodels, and how the projection should be carried out. Explicit calls to `init_refmodel()` and `get_refmodel()` are only rarely needed.

`varsel()`, `cv_varsel()` For running the *search* part and the *evaluation* part for a projection predictive variable selection, possibly with cross-validation (CV).

`summary.vsel()`, `print.vsel()`, `plot.vsel()`, `suggest_size.vsel()`, `ranking()`, `cv_proportions()`, `plot.cv_prop` For post-processing the results from `varsel()` and `cv_varsel()`.

`project()` For projecting the reference model onto submodel(s). Typically, this follows the variable selection, but it can also be applied directly (without a variable selection).

`as.matrix.projection()` For extracting projected parameter draws.

`proj_linpred()`, `proj_predict()` For making predictions from a submodel (after projecting the reference model onto it).

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See Also

Useful links:

- <https://mc-stan.org/projpred/>
- <https://discourse.mc-stan.org>
- Report bugs at <https://github.com/stan-dev/projpred/issues/>

as.matrix.projection *Extract projected parameter draws*

Description

This is the `as.matrix()` method for projection objects (returned by `project()`, possibly as elements of a list). It extracts the projected parameter draws and returns them as a matrix.

Usage

```
## S3 method for class 'projection'
as.matrix(x, nm_scheme = "auto", ...)
```

Arguments

<code>x</code>	An object of class <code>projection</code> (returned by <code>project()</code> , possibly as elements of a list).
<code>nm_scheme</code>	The naming scheme for the columns of the output matrix. Either <code>"auto"</code> , <code>"rstanarm"</code> , or <code>"brms"</code> , where <code>"auto"</code> chooses <code>"rstanarm"</code> or <code>"brms"</code> based on the class of the reference model fit (and uses <code>"rstanarm"</code> if the reference model fit is of an unknown class).
<code>...</code>	Currently ignored.

Details

In case of the augmented-data projection for a multilevel submodel of a `brms::categorical()` reference model, the multilevel parameters (and therefore also their names) slightly differ from those in the `brms` reference model fit (see section "Augmented-data projection" in `extend_family()`'s documentation).

Value

An $S_{\text{prj}} \times Q$ matrix of projected draws, with S_{prj} denoting the number of projected draws and Q the number of parameters.

Examples

```

if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Projection onto an arbitrary combination of predictor terms (with a small
  # value for `nclusters`, but only for the sake of speed in this example;
  # this is not recommended in general):
  prj <- project(fit, solution_terms = c("X1", "X3", "X5"), nclusters = 10,
    seed = 9182)
  prjmat <- as.matrix(prj)
  ### For further post-processing (e.g., via packages `bayesplot` and
  ### `posterior`), we will here ignore the fact that clustering was used
  ### (due to argument `nclusters` above). CAUTION: Ignoring the clustering
  ### is not recommended and only shown here for demonstrative purposes. A
  ### better solution for the clustering case is explained below.
  # If the `bayesplot` package is installed, the output from
  # as.matrix.projection() can be used there. For example:
  if (requireNamespace("bayesplot", quietly = TRUE)) {
    print(bayesplot::mcmc_intervals(prjmat))
  }
  # If the `posterior` package is installed, the output from
  # as.matrix.projection() can be used there. For example:
  if (requireNamespace("posterior", quietly = TRUE)) {
    prjdrws <- posterior::as_draws_matrix(prjmat)
    print(posterior::summarize_draws(
      prjdrws,
      "median", "mad", function(x) quantile(x, probs = c(0.025, 0.975))
    ))
  }
  ### Better solution for post-processing clustered draws (e.g., via
  ### `bayesplot` or `posterior`): Don't ignore the fact that clustering was
  ### used. Instead, resample the clusters according to their weights (e.g.,
  ### via posterior::resample_draws()). However, this requires access to the
  ### cluster weights which is not implemented in `projpred` yet. This
  ### example will be extended as soon as those weights are accessible.
}

```

Description

This is the function which has to be supplied to `extend_family()`'s argument `augdat_illink` in case of the augmented-data projection for the `binomial()` family.

Usage

```
augdat_illink_binom(eta_arr, link = "logit")
```

Arguments

<code>eta_arr</code>	An array as described in section "Augmented-data projection" of <code>extend_family()</code> 's documentation.
<code>link</code>	The same as argument <code>link</code> of <code>binomial()</code> .

Value

An array as described in section "Augmented-data projection" of `extend_family()`'s documentation.

<code>augdat_link_binom</code>	<i>Link function for augmented-data projection with binomial family</i>
--------------------------------	---

Description

This is the function which has to be supplied to `extend_family()`'s argument `augdat_link` in case of the augmented-data projection for the `binomial()` family.

Usage

```
augdat_link_binom(prb_arr, link = "logit")
```

Arguments

<code>prb_arr</code>	An array as described in section "Augmented-data projection" of <code>extend_family()</code> 's documentation.
<code>link</code>	The same as argument <code>link</code> of <code>binomial()</code> .

Value

An array as described in section "Augmented-data projection" of `extend_family()`'s documentation.

break_up_matrix_term	<i>Break up matrix terms</i>
----------------------	------------------------------

Description

Sometimes there can be terms in a formula that refer to a matrix instead of a single predictor. This function breaks up the matrix term into individual predictors to handle separately, as that is probably the intention of the user.

Usage

```
break_up_matrix_term(formula, data)
```

Arguments

formula	A formula for a valid model.
data	The original data.frame with a matrix as predictor.

Value

A list containing the expanded [formula](#) and the expanded data.frame.

cl_agg	<i>Weighted averaging within clusters of parameter draws</i>
--------	--

Description

This function aggregates S parameter draws that have been clustered into S_{cl} clusters by averaging across the draws that belong to the same cluster. This averaging can be done in a weighted fashion.

Usage

```
cl_agg(
  draws,
  cl = seq_len(nrow(draws)),
  wdraws = rep(1, nrow(draws)),
  eps_wdraws = 0
)
```

Arguments

<code>draws</code>	An $S \times P$ matrix of parameter draws, with P denoting the number of parameters.
<code>cl</code>	A numeric vector of length S , giving the cluster indices for the draws. Draws that should be dropped (e.g., by thinning) need to have an NA in <code>cl</code> .
<code>wdraws</code>	A numeric vector of length S , giving the weights of the draws. It doesn't matter whether these are normalized (i.e., sum to 1) or not because internally, these weights are normalized to sum to 1 within each cluster. Draws that should be dropped (e.g., by thinning) can (but must not necessarily) have an NA in <code>wdraws</code> .
<code>eps_wdraws</code>	A positive numeric value (typically small) which will be used to improve numerical stability: The weights of the draws within each cluster are multiplied by $1 - \text{eps_wdraws}$. The default of 0 should be fine for most cases; this argument only exists to help in those cases where numerical instabilities occur (which must be detected by the user; this function will not detect numerical instabilities itself).

Value

An $S_{cl} \times P$ matrix of aggregated parameter draws.

Examples

```
set.seed(323)
S <- 100L
P <- 3L
draws <- matrix(rnorm(S * P), nrow = S, ncol = P)
# Clustering example:
S_cl <- 10L
cl_draws <- sample.int(S_cl, size = S, replace = TRUE)
draws_cl <- cl_agg(draws, cl = cl_draws)
# Clustering example with nonconstant `wdraws`:
w_draws <- rgamma(S, shape = 4)
draws_cl <- cl_agg(draws, cl = cl_draws, wdraws = w_draws)
# Thinning example (implying constant `wdraws`):
S_th <- 50L
idxs_thin <- round(seq(1, S, length.out = S_th))
th_draws <- rep(NA, S)
th_draws[idxs_thin] <- seq_len(S_th)
draws_th <- cl_agg(draws, cl = th_draws)
```

cv-indices

Create cross-validation folds

Description

These are helper functions to create cross-validation (CV) folds, i.e., to split up the indices from 1 to n into K subsets ("folds") for K -fold CV. These functions are potentially useful when creating the `cvfits` and `cvfun` arguments for `init_refmodel()`. Function `cvfolds()` is deprecated; please use `cv_folds()` instead (apart from the name, they are the same). The return value of `cv_folds()` and `cv_ids()` is different, see below for details.

Usage

```
cv_folds(n, K, seed = NA)

cvfolds(n, K, seed = NA)

cv_ids(n, K, out = c("foldwise", "indices"), seed = NA)
```

Arguments

n	Number of observations.
K	Number of folds. Must be at least 2 and not exceed n.
seed	Pseudorandom number generation (PRNG) seed by which the same results can be obtained again if needed. Passed to argument seed of <code>set.seed()</code> , but can also be NA to not call <code>set.seed()</code> at all. If not NA, then the PRNG state is reset (to the state before calling <code>cv_folds()</code> or <code>cv_ids()</code>) upon exiting <code>cv_folds()</code> or <code>cv_ids()</code> .
out	Format of the output, either "foldwise" or "indices". See below for details.

Value

`cv_folds()` returns a vector of length n such that each element is an integer between 1 and K denoting which fold the corresponding data point belongs to. The return value of `cv_ids()` depends on the out argument. If out = "foldwise", the return value is a list with K elements, each being a list with elements tr and ts giving the training and test indices, respectively, for the corresponding fold. If out = "indices", the return value is a list with elements tr and ts each being a list with K elements giving the training and test indices, respectively, for each fold.

Examples

```
n <- 100
set.seed(1234)
y <- rnorm(n)
cv <- cv_ids(n, K = 5)
# Mean within the test set of each fold:
cvmeans <- sapply(cv, function(fold) mean(y[fold$ts]))
```

cv_proportions

Ranking proportions from fold-wise predictor rankings

Description

Calculates the *ranking proportions* from the fold-wise predictor rankings in a cross-validation (CV) with fold-wise searches. For a given predictor x and a given submodel size j , the ranking proportion is the proportion of CV folds which have predictor x at position j of their predictor ranking. While these ranking proportions are helpful for investigating variability in the predictor ranking, they can also be *cumulated* across submodel sizes. The cumulated ranking proportions are more helpful when it comes to model selection.

Usage

```
cv_proportions(object, ...)

## S3 method for class 'ranking'
cv_proportions(object, cumulate = FALSE, ...)

## S3 method for class 'vsel'
cv_proportions(object, ...)
```

Arguments

object	For <code>cv_proportions.ranking()</code> : an object of class <code>ranking</code> (returned by <code>ranking()</code>). For <code>cv_proportions.vsel()</code> : an object of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>) that <code>ranking()</code> will be applied to internally before then calling <code>cv_proportions.ranking()</code> .
...	For <code>cv_proportions.vsel()</code> : arguments passed to <code>ranking.vsel()</code> and <code>cv_proportions.ranking()</code> . For <code>cv_proportions.ranking()</code> : currently ignored.
cumulate	A single logical value indicating whether the ranking proportions should be cumulated across increasing submodel sizes (TRUE) or not (FALSE).

Value

A numeric matrix containing the ranking proportions. This matrix has `nterms_max` rows and `nterms_max` columns, with `nterms_max` as specified in the (possibly implicit) `ranking()` call. The rows correspond to the submodel sizes and the columns to the predictor terms (sorted according to the full-data predictor ranking). If `cumulate` is FALSE, then the returned matrix is of class `cv_proportions`. If `cumulate` is TRUE, then the returned matrix is of classes `cv_proportions_cumul` and `cv_proportions` (in this order).

Note that if `cumulate` is FALSE, then the values in the returned matrix only need to sum to 1 (column-wise and row-wise) if `nterms_max` (see above) is equal to the full model size. Likewise, if `cumulate` is TRUE, then the value 1 only needs to occur in each column of the returned matrix if `nterms_max` is equal to the full model size.

The `cv_proportions()` function is only applicable if the `ranking` object includes fold-wise predictor rankings (i.e., if it is based on a `vsel` object created by `cv_varsel()` with `validate_search = TRUE`). If the `ranking` object contains only a full-data predictor ranking (i.e., if it is based on a `vsel` object created by `varsel()` or by `cv_varsel()`, but the latter with `validate_search = FALSE`), then an error is thrown because in that case, there are no fold-wise predictor rankings from which to calculate ranking proportions.

See Also

`plot.cv_proportions()`

Examples

```
# For an example, see `?plot.cv_proportions`.
```

cv_varsel

*Run search and performance evaluation with cross-validation***Description**

Run the *search* part and the *evaluation* part for a projection predictive variable selection. The search part determines the solution path, i.e., the best submodel for each submodel size (number of predictor terms). The evaluation part determines the predictive performance of the submodels along the solution path. In contrast to `varsel()`, `cv_varsel()` performs a cross-validation (CV) by running the search part with the training data of each CV fold separately (an exception is explained in section "Note" below) and running the evaluation part on the corresponding test set of each CV fold.

Usage

```
cv_varsel(object, ...)

## Default S3 method:
cv_varsel(object, ...)

## S3 method for class 'refmodel'
cv_varsel(
  object,
  method = NULL,
  cv_method = if (!inherits(object, "datafit")) "L00" else "kfold",
  ndraws = NULL,
  nclusters = 20,
  ndraws_pred = 400,
  nclusters_pred = NULL,
  refit_prj = !inherits(object, "datafit"),
  nterms_max = NULL,
  penalty = NULL,
  verbose = TRUE,
  nloo = NULL,
  K = if (!inherits(object, "datafit")) 5 else 10,
  lambda_min_ratio = 1e-05,
  nlambdas = 150,
  thresh = 1e-06,
  regul = 1e-04,
  validate_search = TRUE,
  seed = NA,
  search_terms = NULL,
  ...
)
```

Arguments

object	An object of class <code>refmodel</code> (returned by <code>get_refmodel()</code> or <code>init_refmodel()</code>) or an object that can be passed to argument <code>object</code> of <code>get_refmodel()</code> .
...	Arguments passed to <code>get_refmodel()</code> as well as to the divergence minimizer (during a forward search and also during the evaluation part, but the latter only if <code>refit_prj</code> is TRUE).
method	The method for the search part. Possible options are "L1" for L1 search and "forward" for forward search. If NULL, then internally, "L1" is used, except if (i) the reference model has multilevel or additive terms, (ii) if <code>!is.null(search_terms)</code> , or (iii) if the augmented-data projection is used. See also section "Details" below.
cv_method	The CV method, either "LOO" or "kfold". In the "LOO" case, a Pareto-smoothed importance sampling leave-one-out CV (PSIS-LOO CV) is performed, which avoids refitting the reference model <code>nloo</code> times (in contrast to a standard LOO CV). In the "kfold" case, a <i>K</i> -fold CV is performed.
ndraws	Number of posterior draws used in the search part. Ignored if <code>nclusters</code> is not NULL or in case of L1 search (because L1 search always uses a single cluster). If both (<code>nclusters</code> and <code>ndraws</code>) are NULL, the number of posterior draws from the reference model is used for <code>ndraws</code> . See also section "Details" below.
nclusters	Number of clusters of posterior draws used in the search part. Ignored in case of L1 search (because L1 search always uses a single cluster). For the meaning of NULL, see argument <code>ndraws</code> . See also section "Details" below.
ndraws_pred	Only relevant if <code>refit_prj</code> is TRUE. Number of posterior draws used in the evaluation part. Ignored if <code>nclusters_pred</code> is not NULL. If both (<code>nclusters_pred</code> and <code>ndraws_pred</code>) are NULL, the number of posterior draws from the reference model is used for <code>ndraws_pred</code> . See also section "Details" below.
nclusters_pred	Only relevant if <code>refit_prj</code> is TRUE. Number of clusters of posterior draws used in the evaluation part. For the meaning of NULL, see argument <code>ndraws_pred</code> . See also section "Details" below.
refit_prj	A single logical value indicating whether to fit the submodels along the solution path again (TRUE) or to retrieve their fits from the search part (FALSE) before using those (re-)fits in the evaluation part.
nterms_max	Maximum submodel size (number of predictor terms) up to which the search is continued. If NULL, then <code>min(19, D)</code> is used where <i>D</i> is the number of terms in the reference model (or in <code>search_terms</code> , if supplied). Note that <code>nterms_max</code> does not count the intercept, so use <code>nterms_max = 0</code> for the intercept-only model. (Correspondingly, <i>D</i> above does not count the intercept.)
penalty	Only relevant for L1 search. A numeric vector determining the relative penalties or costs for the predictors. A value of 0 means that those predictors have no cost and will therefore be selected first, whereas <code>Inf</code> means those predictors will never be selected. If NULL, then 1 is used for each predictor.
verbose	A single logical value indicating whether to print out additional information during the computations.

nloo	Caution: Still experimental. Only relevant if <code>cv_method = "LOO"</code> . Number of subsampled LOO CV folds, i.e., number of observations used for the LOO CV (anything between 1 and the original number of observations). Smaller values lead to faster computation but higher uncertainty in the evaluation part. If NULL, all observations are used, but for faster experimentation, one can set this to a smaller value.
K	Only relevant if <code>cv_method = "kfold"</code> and if the reference model was created with <code>cvfits</code> being NULL (which is the case for <code>get_refmodel.stanreg()</code> and <code>brms::get_refmodel.brmsfit()</code>). Number of folds in K -fold CV.
lambda_min_ratio	Only relevant for L1 search. Ratio between the smallest and largest lambda in the L1-penalized search. This parameter essentially determines how long the search is carried out, i.e., how large submodels are explored. No need to change this unless the program gives a warning about this.
nlambda	Only relevant for L1 search. Number of values in the lambda grid for L1-penalized search. No need to change this unless the program gives a warning about this.
thresh	Only relevant for L1 search. Convergence threshold when computing the L1 path. Usually, there is no need to change this.
regul	A number giving the amount of ridge regularization when projecting onto (i.e., fitting) submodels which are GLMs. Usually there is no need for regularization, but sometimes we need to add some regularization to avoid numerical problems.
validate_search	Only relevant if <code>cv_method = "LOO"</code> . A single logical value indicating whether to cross-validate also the search part, i.e., whether to run the search separately for each CV fold (TRUE) or not (FALSE). We strongly do not recommend setting this to FALSE, because this is known to bias the predictive performance estimates of the selected submodels. However, setting this to FALSE can sometimes be useful because comparing the results to the case where this argument is TRUE gives an idea of how strongly the search is (over-)fitted to the data (the difference corresponds to the search degrees of freedom or the effective number of parameters introduced by the search).
seed	Pseudorandom number generation (PRNG) seed by which the same results can be obtained again if needed. Passed to argument <code>seed</code> of <code>set.seed()</code> , but can also be NA to not call <code>set.seed()</code> at all. If not NA, then the PRNG state is reset (to the state before calling <code>cv_varsel()</code>) upon exiting <code>cv_varsel()</code> . Here, <code>seed</code> is used for clustering the reference model's posterior draws (if <code>!is.null(nclusters)</code> or <code>!is.null(nclusters_pred)</code>), for subsampling LOO CV folds (if <code>nloo</code> is smaller than the number of observations), for sampling the folds in K -fold CV, and for drawing new group-level effects when predicting from a multilevel submodel (however, not yet in case of a GAMM).
search_terms	Only relevant for forward search. A custom character vector of predictor term blocks to consider for the search. Section "Details" below describes more precisely what "predictor term block" means. The intercept ("1") is always included internally via <code>union()</code> , so there's no difference between including it explicitly or omitting it. The default <code>search_terms</code> considers all the terms in the reference model's formula.

Details

Arguments `ndraws`, `nclusters`, `nclusters_pred`, and `ndraws_pred` are automatically truncated at the number of posterior draws in the reference model (which is 1 for `datafits`). Using less draws or clusters in `ndraws`, `nclusters`, `nclusters_pred`, or `ndraws_pred` than posterior draws in the reference model may result in slightly inaccurate projection performance. Increasing these arguments affects the computation time linearly.

For argument `method`, there are some restrictions: For a reference model with multilevel or additive formula terms or a reference model set up for the augmented-data projection, only the forward search is available. Furthermore, argument `search_terms` requires a forward search to take effect.

L1 search is faster than forward search, but forward search may be more accurate. Furthermore, forward search may find a sparser model with comparable performance to that found by L1 search, but it may also start overfitting when more predictors are added.

An L1 search may select interaction terms before the corresponding main terms are selected. If this is undesired, choose the forward search instead.

The elements of the `search_terms` character vector don't need to be individual predictor terms. Instead, they can be building blocks consisting of several predictor terms connected by the `+` symbol. To understand how these building blocks work, it is important to know how **projpred**'s forward search works: It starts with an empty vector chosen which will later contain already selected predictor terms. Then, the search iterates over model sizes $j \in \{1, \dots, J\}$. The candidate models at model size j are constructed from those elements from `search_terms` which yield model size j when combined with the chosen predictor terms. Note that sometimes, there may be no candidate models for model size j . Also note that internally, `search_terms` is expanded to include the intercept ("`1`"), so the first step of the search (model size 1) always consists of the intercept-only model as the only candidate.

As a `search_terms` example, consider a reference model with formula $y \sim x1 + x2 + x3$. Then, to ensure that `x1` is always included in the candidate models, specify `search_terms = c("x1", "x1 + x2", "x1 + x3", "x1 + x2 + x3")`. This search would start with $y \sim 1$ as the only candidate at model size 1. At model size 2, $y \sim x1$ would be the only candidate. At model size 3, $y \sim x1 + x2$ and $y \sim x1 + x3$ would be the two candidates. At the last model size of 4, $y \sim x1 + x2 + x3$ would be the only candidate. As another example, to exclude `x1` from the search, specify `search_terms = c("x2", "x3", "x2 + x3")`.

Value

An object of class `vsel`. The elements of this object are not meant to be accessed directly but instead via helper functions (see the main vignette and [projpred-package](#)).

Note

If `validate_search` is `FALSE`, the search is not included in the CV so that only a single full-data search is run.

For PSIS-LOO CV, **projpred** calls `loo::psis()` with `r_eff = NA`. This is only a problem if there was extreme autocorrelation between the MCMC iterations when the reference model was built. In those cases however, the reference model should not have been used anyway, so we don't expect **projpred**'s `r_eff = NA` to be a problem.

References

- Magnusson, Måns, Michael Andersen, Johan Jonasson, and Aki Vehtari. 2019. "Bayesian Leave-One-Out Cross-Validation for Large Data." In *Proceedings of the 36th International Conference on Machine Learning*, edited by Kamalika Chaudhuri and Ruslan Salakhutdinov, 97:4244–53. Proceedings of Machine Learning Research. PMLR. <https://proceedings.mlr.press/v97/magnusson19a.html>.
- Vehtari, Aki, Andrew Gelman, and Jonah Gabry. 2017. "Practical Bayesian Model Evaluation Using Leave-One-Out Cross-Validation and WAIC." *Statistics and Computing* 27 (5): 1413–32. [doi:10.1007/s1122201696964](https://doi.org/10.1007/s1122201696964).
- Vehtari, Aki, Daniel Simpson, Andrew Gelman, Yuling Yao, and Jonah Gabry. 2022. "Pareto Smoothed Importance Sampling." arXiv. [doi:10.48550/arXiv.1507.02646](https://doi.org/10.48550/arXiv.1507.02646).

See Also

`varsel()`

Examples

```
# Note: The code from this example is not executed when called via example().
# To execute it, you have to copy and paste it manually to the console.
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 1000, refresh = 0, seed = 9876
  )

  # Run cv_varsel() (with small values for `K`, `nterms_max`, `nclusters`,
  # and `nclusters_pred`, but only for the sake of speed in this example;
  # this is not recommended in general):
  cvvs <- cv_varsel(fit, cv_method = "kfold", K = 2, nterms_max = 3,
    nclusters = 5, nclusters_pred = 10, seed = 5555)
  # Now see, for example, `?print.vsel`, `?plot.vsel`, `?suggest_size.vsel`,
  # and `?ranking` for possible post-processing functions.
}
```

df_binom

Binomial toy example

Description

Binomial toy example

Usage

df_binom

Format

A simulated classification dataset containing 100 observations.

y response, 0 or 1.

x predictors, 30 in total.

Source

<https://web.stanford.edu/~hastie/glmnet/glmnetData/BNExample.RData>

df_gaussian

Gaussian toy example

Description

Gaussian toy example

Usage

df_gaussian

Format

A simulated regression dataset containing 100 observations.

y response, real-valued.

x predictors, 20 in total. Mean and SD are approximately 0 and 1, respectively.

Source

<https://web.stanford.edu/~hastie/glmnet/glmnetData/QSEExample.RData>

extend_family	<i>Extend a family</i>
---------------	------------------------

Description

This function adds some internally required elements to an object of class `family` (see, e.g., `family()`). It is called internally by `init_refmodel()`, so you will rarely need to call it yourself.

Usage

```
extend_family(
  family,
  latent = FALSE,
  latent_y_unqs = NULL,
  latent_ilink = NULL,
  latent_ll_oscale = NULL,
  latent_ppd_oscale = NULL,
  augdat_y_unqs = NULL,
  augdat_link = NULL,
  augdat_ilink = NULL,
  augdat_args_link = list(),
  augdat_args_ilink = list(),
  ...
)
```

Arguments

<code>family</code>	An object of class <code>family</code> .
<code>latent</code>	A single logical value indicating whether to use the latent projection (TRUE) or not (FALSE). Note that setting <code>latent = TRUE</code> causes all arguments starting with <code>augdat_</code> to be ignored.
<code>latent_y_unqs</code>	Only relevant for a latent projection where the original response space has finite support (i.e., the original response values may be regarded as categories), in which case this needs to be the character vector of unique response values (which will be assigned to <code>family\$cats</code> internally) or may be left at NULL (so that projpred will try to infer it from <code>family\$cats</code>). See also section "Latent projection" below.
<code>latent_ilink</code>	Only relevant for the latent projection, in which case this needs to be the inverse-link function. If the original response family was the <code>binomial()</code> or the <code>poisson()</code> family, then <code>latent_ilink</code> can be NULL, in which case an internal default will be used. Can also be NULL in all other cases, but then an internal default based on <code>family\$linkinv</code> will be used which might not work for all families. See also section "Latent projection" below.
<code>latent_ll_oscale</code>	Only relevant for the latent projection, in which case this needs to be the function computing response-scale (not latent-scale) log-likelihood values. If <code>!is.null(family\$cats)</code>

(after taking `latent_y_unqs` into account) or if the original response family was the `binomial()` or the `poisson()` family, then `latent_ll_yscale` can be `NULL`, in which case an internal default will be used. Can also be `NULL` in all other cases, but then downstream functions will have limited functionality (a message thrown by `extend_family()` will state what exactly won't be available). See also section "Latent projection" below.

`latent_ppd_yscale`

Only relevant for the latent projection, in which case this needs to be the function sampling response values given latent predictors that have been transformed to response scale using `latent_ylink`. If `!is.null(family$cats)` (after taking `latent_y_unqs` into account) or if the original response family was the `binomial()` or the `poisson()` family, then `latent_ppd_yscale` can be `NULL`, in which case an internal default will be used. Can also be `NULL` in all other cases, but then downstream functions will have limited functionality (a message thrown by `extend_family()` will state what exactly won't be available). See also section "Latent projection" below. Note that although this function has the abbreviation "PPD" in its name (which stands for "posterior predictive distribution"), **projpred** currently only uses it in `proj_predict()`, i.e., for sampling from what would better be termed posterior-projection predictive distribution (PPPD).

<code>augdat_y_unqs</code>	Only relevant for augmented-data projection, in which case this needs to be the character vector of unique response values (which will be assigned to <code>family\$cats</code> internally) or may be left at <code>NULL</code> if <code>family\$cats</code> is already non- <code>NULL</code> . See also section "Augmented-data projection" below.
<code>augdat_link</code>	Only relevant for augmented-data projection, in which case this needs to be the link function. Use <code>NULL</code> for the traditional projection. See also section "Augmented-data projection" below.
<code>augdat_ylink</code>	Only relevant for augmented-data projection, in which case this needs to be the inverse-link function. Use <code>NULL</code> for the traditional projection. See also section "Augmented-data projection" below.
<code>augdat_args_link</code>	Only relevant for augmented-data projection, in which case this may be a named list of arguments to pass to the function supplied to <code>augdat_link</code> .
<code>augdat_args_ylink</code>	Only relevant for augmented-data projection, in which case this may be a named list of arguments to pass to the function supplied to <code>augdat_ylink</code> .
<code>...</code>	Ignored (exists only to swallow up further arguments which might be passed to this function).

Details

In the following, N , C_{cat} , C_{lat} , S_{ref} , and S_{prj} from help topic `refmodel-init-get` are used. Note that N does not necessarily denote the number of original observations; it can also refer to new observations. Furthermore, let S denote either S_{ref} or S_{prj} , whichever is appropriate in the context where it is used.

Value

The family object extended in the way needed by **projpred**.

Augmented-data projection

As their first input, the functions supplied to arguments `augdat_link` and `augdat_ilink` have to accept:

- For `augdat_link`: an $S \times N \times C_{\text{cat}}$ array containing the probabilities for the response categories. The order of the response categories is the same as in `family$cats` (see argument `augdat_y_unqs`).
- For `augdat_ilink`: an $S \times N \times C_{\text{lat}}$ array containing the linear predictors.

The return value of these functions needs to be:

- For `augdat_link`: an $S \times N \times C_{\text{lat}}$ array containing the linear predictors.
- For `augdat_ilink`: an $S \times N \times C_{\text{cat}}$ array containing the probabilities for the response categories. The order of the response categories has to be the same as in `family$cats` (see argument `augdat_y_unqs`).

For the augmented-data projection, the response vector resulting from `extract_model_data` (see `init_refmodel()`) is coerced to a factor (using `as.factor()`) at multiple places throughout this package. Inside of `init_refmodel()`, the levels of this factor have to be identical to `family$cats` (after applying `extend_family()` inside of `init_refmodel()`). Everywhere else, these levels have to be a subset of `<refmodel>$family$cats` (where `<refmodel>` is an object resulting from `init_refmodel()`). See argument `augdat_y_unqs` for how to control `family$cats`.

For ordinal **brms** families, be aware that the submodels (onto which the reference model is projected) currently have the following restrictions:

- The discrimination parameter `disc` is not supported (i.e., it is a constant with value 1).
- The thresholds are "flexible" (see `brms::brmsfamily()`).
- The thresholds do not vary across the levels of a factor-like variable (see argument `gr` of `brms::resp_thres()`).
- The "probit_approx" link is replaced by "probit".

For the `brms::categorical()` family, be aware that:

- For multilevel submodels, the group-level effects are allowed to be correlated between different response categories.
- For multilevel submodels, **mclogit** versions < 0.9.4 may throw the error 'a' (<number> x 1) must be square. Updating **mclogit** to a version >= 0.9.4 should fix this.

Latent projection

The function supplied to argument `latent_ilink` needs to have the prototype

```
latent_ilink(lpreds, cl_ref, wdraws_ref = rep(1, length(cl_ref)))
```

where:

- `lpreds` accepts an $S \times N$ matrix containing the linear predictors.
- `cl_ref` accepts a numeric vector of length S_{ref} , containing **projpred**'s internal cluster indices for these draws.
- `wdraws_ref` accepts a numeric vector of length S_{ref} , containing weights for these draws. These weights should be treated as not being normalized (i.e., they don't necessarily sum to 1).

The return value of `latent_ilink` needs to contain the linear predictors transformed to the original response space, with the following structure:

- If `is.null(family$cats)` (after taking `latent_y_unqs` into account): an $S \times N$ matrix.
- If `!is.null(family$cats)` (after taking `latent_y_unqs` into account): an $S \times N \times C_{\text{cat}}$ array. In that case, `latent_ilink` needs to return *probabilities* (for the response categories given in `family$cats`, after taking `latent_y_unqs` into account).

The function supplied to argument `latent_ll_oscale` needs to have the prototype

```
latent_ll_oscale(ilpreds, y_oscale, wobs = rep(1, length(y_oscale)), cl_ref,
                 wdraws_ref = rep(1, length(cl_ref)))
```

where:

- `ilpreds` accepts the return value from `latent_ilink`.
- `y_oscale` accepts a vector of length N containing response values on the original response scale.
- `wobs` accepts a numeric vector of length N containing observation weights.
- `cl_ref` accepts the same input as argument `cl_ref` of `latent_ilink`.
- `wdraws_ref` accepts the same input as argument `wdraws_ref` of `latent_ilink`.

The return value of `latent_ll_oscale` needs to be an $S \times N$ matrix containing the response-scale (not latent-scale) log-likelihood values for the N observations from its inputs.

The function supplied to argument `latent_ppd_oscale` needs to have the prototype

```
latent_ppd_oscale(ilpreds_resamp, wobs, cl_ref,
                  wdraws_ref = rep(1, length(cl_ref)), idxs_prjdraws)
```

where:

- `ilpreds_resamp` accepts the return value from `latent_ilink`, but possibly with resampled (clustered) draws (see argument `nresample_clusters` of `proj_predict()`).
- `wobs` accepts a numeric vector of length N containing observation weights.
- `cl_ref` accepts the same input as argument `cl_ref` of `latent_ilink`.
- `wdraws_ref` accepts the same input as argument `wdraws_ref` of `latent_ilink`.
- `idxs_prjdraws` accepts a numeric vector of length `dim(ilpreds_resamp)[1]` containing the resampled indices of the projected draws (i.e., these indices are values from the set $\{1, \dots, \dim(\text{ilpreds})[1]\}$ where `ilpreds` denotes the return value of `latent_ilink`).

The return value of `latent_ppd_oscale` needs to be a $\text{dim}(\text{ilpreds_resamp})[1] \times N$ matrix containing the response-scale (not latent-scale) draws from the posterior(-projection) predictive distributions for the N observations from its inputs.

If the bodies of these three functions involve parameter draws from the reference model which have not been projected (e.g., for `latent_iliink`, the thresholds in an ordinal model), `cl_agg()` is provided as a helper function for aggregating these reference model draws in the same way as the draws have been aggregated for the first argument of these functions (e.g., `lpreds` in case of `latent_iliink`).

In fact, the weights passed to argument `wdraws_ref` are nonconstant only in case of `cv_varssel()` with `cv_method = "LOO"` and `validate_search = TRUE`. In that case, the weights passed to this argument are the PSIS-LOO CV weights for one observation. Note that although argument `wdraws_ref` has the suffix `_ref`, `wdraws_ref` does not necessarily obtain weights for the *initial* reference model's posterior draws: In case of `cv_varssel()` with `cv_method = "kfold"`, these weights may refer to one of the K reference model re-fits (but in that case, they are constant anyway).

If `family$cats` is not NULL (after taking `latent_y_unqs` into account), then the response vector resulting from `extract_model_data` (see `init_refmodel()`) is coerced to a factor (using `as.factor()`) at multiple places throughout this package. Inside of `init_refmodel()`, the levels of this factor have to be identical to `family$cats` (after applying `extend_family()` inside of `init_refmodel()`). Everywhere else, these levels have to be a subset of `<refmodel>$family$cats` (where `<refmodel>` is an object resulting from `init_refmodel()`).

 extra-families

Extra family objects

Description

Family objects not in the set of default `family` objects.

Usage

```
Student_t(link = "identity", nu = 3)
```

Arguments

<code>link</code>	Name of the link function. In contrast to the default <code>family</code> objects, this has to be a character string here.
<code>nu</code>	Degrees of freedom for the Student- t distribution.

Value

A family object analogous to those described in `family`.

Note

Support for the `Student_t()` family is still experimental.

mesquite

*Mesquite data set***Description**

The mesquite bushes yields dataset from Gelman and Hill (2006) (<http://www.stat.columbia.edu/~gelman/arm/>).

Usage

```
mesquite
```

Format

The response variable is the total weight (in grams) of photosynthetic material as derived from actual harvesting of the bush. The predictor variables are:

diam1 diameter of the canopy (the leafy area of the bush) in meters, measured along the longer axis of the bush.

diam2 canopy diameter measured along the shorter axis.

canopy height height of the canopy.

total height total height of the bush.

density plant unit density (# of primary stems per plant unit).

group group of measurements (0 for the first group, 1 for the second group).

Source

<http://www.stat.columbia.edu/~gelman/arm/examples/mesquite/mesquite.dat>

References

Gelman, Andrew, and Jennifer Hill. 2006. *Data Analysis Using Regression and Multilevel/Hierarchical Models*. Cambridge, UK: Cambridge University Press. doi:10.1017/CBO9780511790942.

plot.cv_proportions

*Plot ranking proportions from fold-wise predictor rankings***Description**

Plots the ranking proportions (see [cv_proportions\(\)](#)) from the fold-wise predictor rankings in a cross-validation with fold-wise searches. This is a visualization of the *transposed* matrix returned by [cv_proportions\(\)](#). The proportions printed as text inside of the colored tiles are rounded to whole percentage points (the plotted proportions themselves are not rounded).

Usage

```
## S3 method for class 'cv_proportions'
plot(x, text_angle = NULL, ...)

## S3 method for class 'ranking'
plot(x, ...)
```

Arguments

x	For <code>plot.cv_proportions()</code> : an object of class <code>cv_proportions</code> (returned by <code>cv_proportions()</code> , possibly with <code>cumulate = TRUE</code>). For <code>plot.ranking()</code> : an object of class <code>ranking</code> (returned by <code>ranking()</code>) that <code>cv_proportions()</code> will be applied to internally before then calling <code>plot.cv_proportions()</code> .
text_angle	Passed to argument <code>angle</code> of <code>ggplot2::element_text()</code> for the y-axis tick labels. In case of long predictor names, <code>text_angle = 45</code> might be helpful (for example).
...	For <code>plot.ranking()</code> : arguments passed to <code>cv_proportions.ranking()</code> and <code>plot.cv_proportions()</code> . For <code>plot.cv_proportions()</code> : currently ignored.

Value

A **ggplot2** plotting object (of class `gg` and `ggplot`).

Author(s)

Idea and original code by Aki Vehtari. Slight modifications of the original code by Frank Weber, Yann McLatchie, and Sölvi Rögnvaldsson. Final implementation in **projpred** by Frank Weber.

Examples

```
# Note: The code from this example is not executed when called via example().
# To execute it, you have to copy and paste it manually to the console.
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 1000, refresh = 0, seed = 9876
  )

  # Run cv_varsel() (with small values for `K`, `nterms_max`, `nclusters`,
  # and `nclusters_pred`, but only for the sake of speed in this example;
  # this is not recommended in general):
  cvvs <- cv_varsel(fit, cv_method = "kfold", K = 2, nterms_max = 3,
    nclusters = 5, nclusters_pred = 10, seed = 5555)
```

```

# Extract predictor rankings:
rk <- ranking(cvvs)

# Compute ranking proportions:
pr_rk <- cv_proportions(rk)

# Visualize the ranking proportions:
gg_pr_rk <- plot(pr_rk)
print(gg_pr_rk)

# Since the object returned by plot.cv_proportions() is a standard ggplot2
# plotting object, you can modify the plot easily, e.g., to remove the
# legend:
print(gg_pr_rk + theme(legend.position = "none"))
}

```

plot.vsel

Plot predictive performance

Description

This is the `plot()` method for `vsel` objects (returned by `varsel()` or `cv_varsel()`). It visualizes the predictive performance of the reference model (possibly also that of some other "baseline" model) and that of the submodels along the full-data predictor ranking. Basic information about the (CV) variability in the ranking of the predictors is included as well (if available; inferred from `cv_proportions()`). For a tabular representation, see `summary.vsel()`.

Usage

```

## S3 method for class 'vsel'
plot(
  x,
  nterms_max = NULL,
  stats = "elpd",
  deltas = FALSE,
  alpha = 2 * pnorm(-1),
  baseline = if (!inherits(x$refmodel, "datafit")) "ref" else "best",
  thres_elpd = NA,
  resp_oscale = TRUE,
  ranking_nterms_max = NULL,
  ranking_abbreviate = FALSE,
  ranking_abbreviate_args = list(),
  ranking_repel = NULL,
  ranking_repel_args = list(),
  cumulate = FALSE,
  text_angle = NULL,
  ...
)

```

Arguments

x	An object of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>).
nterms_max	Maximum submodel size (number of predictor terms) for which the performance statistics are calculated. Using <code>NULL</code> is effectively the same as <code>length(ranking(object)[["fulldata"]])</code> . Note that <code>nterms_max</code> does not count the intercept, so use <code>nterms_max = 0</code> for the intercept-only model. For <code>plot.vsel()</code> , <code>nterms_max</code> must be at least 1.
stats	One or more character strings determining which performance statistics (i.e., utilities or losses) to estimate based on the observations in the evaluation (or "test") set (in case of cross-validation, these are all observations because they are partitioned into multiple test sets; in case of <code>varsel()</code> with <code>d_test = NULL</code> , these are again all observations because the test set is the same as the training set). Available statistics are: <ul style="list-style-type: none"> • "elpd": expected log (pointwise) predictive density (for a new dataset). Estimated by the sum of the observation-specific log predictive density values (with each of these predictive density values being a—possibly weighted—average across the parameter draws). • "mlpd": mean log predictive density, that is, "elpd" divided by the number of observations. • "mse": mean squared error (only available in the situations mentioned in section "Details" below). • "rmse": root mean squared error (only available in the situations mentioned in section "Details" below). For the corresponding standard error and lower and upper confidence interval bounds, bootstrapping is used. • "acc" (or its alias, "pctcorr"): classification accuracy (only available in the situations mentioned in section "Details" below). • "auc": area under the ROC curve (only available in the situations mentioned in section "Details" below). For the corresponding standard error and lower and upper confidence interval bounds, bootstrapping is used.
deltas	If <code>TRUE</code> , the submodel statistics are estimated as differences from the baseline model (see argument <code>baseline</code>). With a "difference <i>from</i> the baseline model", we mean to take the submodel statistic minus the baseline model statistic (not the other way round).
alpha	A number determining the (nominal) coverage $1 - \alpha$ of the normal-approximation (or bootstrap; see argument <code>stats</code>) confidence intervals. For example, in case of the normal approximation, <code>alpha = 2 * pnorm(-1)</code> corresponds to a confidence interval stretching by one standard error on either side of the point estimate.
baseline	For <code>summary.vsel()</code> : Only relevant if <code>deltas</code> is <code>TRUE</code> . For <code>plot.vsel()</code> : Always relevant. Either "ref" or "best", indicating whether the baseline is the reference model or the best submodel found (in terms of <code>stats[1]</code>), respectively.
thres_elpd	Only relevant if <code>any(stats %in% c("elpd", "mlpd"))</code> . The threshold for the ELPD difference (taking the submodel's ELPD minus the baseline model's ELPD) above which the submodel's ELPD is considered to be close enough to the baseline model's ELPD. An equivalent rule is applied in case of the MLPD. See <code>suggest_size()</code> for a formalization. Supplying <code>NA</code> deactivates this.

<code>resp_oscale</code>	Only relevant for the latent projection. A single logical value indicating whether to calculate the performance statistics on the original response scale (TRUE) or on latent scale (FALSE).
<code>ranking_nterms_max</code>	Maximum submodel size (number of predictor terms) for which the predictor names and the corresponding ranking proportions are added on the x-axis. Using NULL is effectively the same as using <code>nterms_max</code> . Using NA causes the predictor names and the corresponding ranking proportions to be omitted. Note that <code>ranking_nterms_max</code> does not count the intercept, so <code>ranking_nterms_max = 1</code> corresponds to the submodel consisting of the first (non-intercept) predictor term.
<code>ranking_abbreviate</code>	A single logical value indicating whether the predictor names in the full-data predictor ranking should be abbreviated by <code>abbreviate()</code> (TRUE) or not (FALSE). See also argument <code>ranking_abbreviate_args</code> and section "Value".
<code>ranking_abbreviate_args</code>	A list of arguments (except for <code>names.arg</code>) to be passed to <code>abbreviate()</code> in case of <code>ranking_abbreviate = TRUE</code> .
<code>ranking_repel</code>	Either NULL, "text", or "label". By NULL, the full-data predictor ranking and the corresponding ranking proportions are placed below the x-axis. By "text" or "label", they are placed within the plotting area, using <code>ggrepel::geom_text_repel()</code> or <code>ggrepel::geom_label_repel()</code> , respectively. See also argument <code>ranking_repel_args</code> .
<code>ranking_repel_args</code>	A list of arguments (except for mapping) to be passed to <code>ggrepel::geom_text_repel()</code> or <code>ggrepel::geom_label_repel()</code> in case of <code>ranking_repel = "text"</code> or <code>ranking_repel = "label"</code> , respectively.
<code>cumulate</code>	Passed to argument <code>cumulate</code> of <code>cv_proportions()</code> . Affects the ranking proportions given on the x-axis (below the full-data predictor ranking).
<code>text_angle</code>	Passed to argument <code>angle</code> of <code>ggplot2::element_text()</code> for the x-axis tick labels. In case of long predictor names (and/or large <code>nterms_max</code>), <code>text_angle = 45</code> might be helpful (for example).
<code>...</code>	Arguments passed to the internal function which is used for bootstrapping (if applicable; see argument <code>stats</code>). Currently, relevant arguments are <code>B</code> (the number of bootstrap samples, defaulting to 2000) and <code>seed</code> (see <code>set.seed()</code> , but defaulting to NA so that <code>set.seed()</code> is not called within that function at all).

Details

The stats options "mse" and "rmse" are only available for:

- the traditional projection,
- the latent projection with `resp_oscale = FALSE`,
- the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being NULL.

The stats option "acc" (= "pctcorr") is only available for:

- the `binomial()` family in case of the traditional projection,

- all families in case of the augmented-data projection,
- the `binomial()` family (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being `NULL`,
- all families (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being not `NULL`.

The stats option "auc" is only available for:

- the `binomial()` family in case of the traditional projection,
- the `binomial()` family (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being `NULL`.

Value

A `ggplot2` plotting object (of class `gg` and `ggplot`). If `ranking_abbreviate` is `TRUE`, the output of `abbreviate()` is stored in an attribute called `projpred_ranking_abbreviated` (to allow the abbreviations to be easily mapped back to the original predictor names).

Horizontal lines

As long as the reference model's performance is computable, it is always shown in the plot as a dashed red horizontal line. If `baseline = "best"`, the baseline model's performance is shown as a dotted black horizontal line. If `!is.na(thres_elpd)` and `any(stats %in% c("elpd", "mlpd"))`, the value supplied to `thres_elpd` (which is automatically adapted internally in case of the MLPD or `deltas = FALSE`) is shown as a dot-dashed gray horizontal line for the reference model and, if `baseline = "best"`, as a long-dashed green horizontal line for the baseline model.

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Run varsel() (here without cross-validation and with small values for
  # `nterms_max`, `nclusters`, and `nclusters_pred`, but only for the sake of
  # speed in this example; this is not recommended in general):
  vs <- varsel(fit, nterms_max = 3, nclusters = 5, nclusters_pred = 10,
               seed = 5555)
  print(plot(vs))
}
```

 pred-projection

Predictions from a submodel (after projection)

Description

After the projection of the reference model onto a submodel, the linear predictors (for the original or a new dataset) based on that submodel can be calculated by `proj_linpred()`. These linear predictors can also be transformed to response scale and averaged across the projected parameter draws. Furthermore, `proj_linpred()` returns the corresponding log predictive density values if the (original or new) dataset contains response values. The `proj_predict()` function draws from the predictive distributions (there is one such distribution for each observation from the original or new dataset) of the submodel that the reference model has been projected onto. If the projection has not been performed yet, both functions call `project()` internally to perform the projection. Both functions can also handle multiple submodels at once (for objects of class `vsel` or objects returned by a `project()` call to an object of class `vsel`; see `project()`).

Usage

```
proj_linpred(
  object,
  newdata = NULL,
  offsetnew = NULL,
  weightsnew = NULL,
  filter_nterms = NULL,
  transform = FALSE,
  integrated = FALSE,
  .seed = NA,
  ...
)

proj_predict(
  object,
  newdata = NULL,
  offsetnew = NULL,
  weightsnew = NULL,
  filter_nterms = NULL,
  nresample_clusters = 1000,
  .seed = NA,
  resp_oscale = TRUE,
  ...
)
```

Arguments

<code>object</code>	An object returned by <code>project()</code> or an object that can be passed to argument <code>object</code> of <code>project()</code> .
---------------------	--

newdata	Passed to argument newdata of the reference model's extract_model_data function (see init_refmodel()). Provides the predictor (and possibly also the response) data for the new (or old) observations. May also be NULL (see argument extract_model_data of init_refmodel()). If not NULL, any NAs will trigger an error.
offsetnew	Passed to argument orhs of the reference model's extract_model_data function (see init_refmodel()). Used to get the offsets for the new (or old) observations.
weightsnew	Passed to argument wrhs of the reference model's extract_model_data function (see init_refmodel()). Used to get the weights for the new (or old) observations.
filter_nterms	Only applies if object is an object returned by project() . In that case, filter_nterms can be used to filter object for only those elements (submodels) with a number of solution terms in filter_nterms. Therefore, needs to be a numeric vector or NULL. If NULL, use all submodels.
transform	For proj_linpred() only. A single logical value indicating whether the linear predictor should be transformed to response scale using the inverse-link function (TRUE) or not (FALSE). In case of the latent projection, argument transform is similar in spirit to argument resp_oscale from other functions and affects the scale of both output elements pred and lpd (see sections "Details" and "Value" below).
integrated	For proj_linpred() only. A single logical value indicating whether the output should be averaged across the projected posterior draws (TRUE) or not (FALSE).
.seed	Pseudorandom number generation (PRNG) seed by which the same results can be obtained again if needed. Passed to argument seed of set.seed() , but can also be NA to not call set.seed() at all. If not NA, then the PRNG state is reset (to the state before calling proj_linpred() or proj_predict()) upon exiting proj_linpred() or proj_predict() . Here, .seed is used for drawing new group-level effects in case of a multilevel submodel (however, not yet in case of a GAMM) and for drawing from the predictive distributions of the submodel(s) in case of proj_predict() . If a clustered projection was performed, then in proj_predict() , .seed is also used for drawing from the set of projected clusters of posterior draws (see argument nresample_clusters). If project() is called internally with seed = NA (or with seed being a lazily evaluated expression that uses the PRNG), then .seed also affects the PRNG usage there.
...	Arguments passed to project() if object is not already an object returned by project() .
nresample_clusters	For proj_predict() with clustered projection only. Number of draws to return from the predictive distributions of the submodel(s). Not to be confused with argument nclusters of project() : nresample_clusters gives the number of draws (with replacement) from the set of clustered posterior draws after projection (with this set being determined by argument nclusters of project()).
resp_oscale	Only relevant for the latent projection. A single logical value indicating whether to draw from the posterior-projection predictive distributions on the original response scale (TRUE) or on latent scale (FALSE).

Details

Currently, `proj_predict()` ignores observation weights that are not equal to 1. A corresponding warning is thrown if this is the case.

In case of the latent projection and `transform = FALSE`:

- Output element `pred` contains the linear predictors without any modifications that may be due to the original response distribution (e.g., for a `brms::cumulative()` model, the ordered thresholds are not taken into account).
- Output element `lpd` contains the *latent* log predictive density values, i.e., those corresponding to the latent Gaussian distribution. If `newdata` is not `NULL`, this requires the latent response values to be supplied in a column called `.<response_name>` of `newdata` where `<response_name>` needs to be replaced by the name of the original response variable (if `<response_name>` contained parentheses, these have been stripped off by `init_refmodel()`; see the left-hand side of `formula(<refmodel>)`). For technical reasons, the existence of column `<response_name>` in `newdata` is another requirement (even though `.<response_name>` is actually used).

Value

In the following, S_{prj} , N , C_{cat} , and C_{lat} from help topic `refmodel-init-get` are used. (For `proj_linpred()` with `integrated = TRUE`, we have $S_{\text{prj}} = 1$.) Furthermore, let C denote either C_{cat} (if `transform = TRUE`) or C_{lat} (if `transform = FALSE`). Then, if the prediction is done for one submodel only (i.e., `length(nterms) == 1` || `!is.null(solution_terms)` in the call to `project()`):

- `proj_linpred()` returns a list with the following elements:
 - Element `pred` contains the actual predictions, i.e., the linear predictors, possibly transformed to response scale (depending on argument `transform`).
 - Element `lpd` is non-`NULL` only if `newdata` is `NULL` or if `newdata` contains response values in the corresponding column. In that case, it contains the log predictive density values (conditional on each of the projected parameter draws if `integrated = FALSE` and averaged across the projected parameter draws if `integrated = TRUE`).

In case of (i) the traditional projection, (ii) the latent projection with `transform = FALSE`, or (iii) the latent projection with `transform = TRUE` and `<refmodel>$family$cats` (where `<refmodel>` is an object resulting from `init_refmodel()`; see also `extend_family()`'s argument `latent_y_unqs`) being `NULL`, both elements are $S_{\text{prj}} \times N$ matrices. In case of (i) the augmented-data projection or (ii) the latent projection with `transform = TRUE` and `<refmodel>$family$cats` being not `NULL`, `pred` is an $S_{\text{prj}} \times N \times C$ array and `lpd` is an $S_{\text{prj}} \times N$ matrix.

- `proj_predict()` returns an $S_{\text{prj}} \times N$ matrix of predictions where S_{prj} denotes `nresample_clusters` in case of clustered projection. In case of (i) the augmented-data projection or (ii) the latent projection with `resp_yscale = TRUE` and `<refmodel>$family$cats` being not `NULL`, this matrix has an attribute called `cats` (the character vector of response categories) and the values of the matrix are the predicted indices of the response categories (these indices refer to the order of the response categories from attribute `cats`).

If the prediction is done for more than one submodel, the output from above is returned for each submodel, giving a named list with one element for each submodel (the names of this list being the numbers of solution terms of the submodels when counting the intercept, too).

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Projection onto an arbitrary combination of predictor terms (with a small
  # value for `nclusters`, but only for the sake of speed in this example;
  # this is not recommended in general):
  prj <- project(fit, solution_terms = c("X1", "X3", "X5"), nclusters = 10,
    seed = 9182)

  # Predictions (at the training points) from the submodel onto which the
  # reference model was projected:
  prjl <- proj_linpred(prj)
  prjp <- proj_predict(prj, .seed = 7364)
}
```

predict.refmodel	<i>Predictions or log posterior predictive densities from a reference model</i>
------------------	---

Description

This is the `predict()` method for `refmodel` objects (returned by `get_refmodel()` or `init_refmodel()`). It offers three types of output which are all based on the reference model and new (or old) observations: Either the linear predictor on link scale, the linear predictor transformed to response scale, or the log posterior predictive density.

Usage

```
## S3 method for class 'refmodel'
predict(
  object,
  newdata = NULL,
  ynew = NULL,
  offsetnew = NULL,
  weightsnew = NULL,
  type = "response",
  ...
)
```

Arguments

object	An object of class <code>refmodel</code> (returned by <code>get_refmodel()</code> or <code>init_refmodel()</code>).
newdata	Passed to argument <code>newdata</code> of the reference model's <code>extract_model_data</code> function (see <code>init_refmodel()</code>). Provides the predictor (and possibly also the response) data for the new (or old) observations. May also be <code>NULL</code> (see argument <code>extract_model_data</code> of <code>init_refmodel()</code>). If not <code>NULL</code> , any NAs will trigger an error.
ynew	If not <code>NULL</code> , then this needs to be a vector of new (or old) response values. See also section "Value" below. In case of (i) the augmented-data projection or (ii) the latent projection with <code>type = "response"</code> and <code>object\$family\$cats</code> being not <code>NULL</code> , <code>ynew</code> is internally coerced to a factor (using <code>as.factor()</code>). The levels of this factor have to be a subset of <code>object\$family\$cats</code> (see <code>extend_family()</code> 's arguments <code>augdat_y_unqs</code> and <code>latent_y_unqs</code> , respectively).
offsetnew	Passed to argument <code>orhs</code> of the reference model's <code>extract_model_data</code> function (see <code>init_refmodel()</code>). Used to get the offsets for the new (or old) observations.
weightsnew	Passed to argument <code>wrhs</code> of the reference model's <code>extract_model_data</code> function (see <code>init_refmodel()</code>). Used to get the weights for the new (or old) observations.
type	Usually only relevant if <code>is.null(ynew)</code> , but for the latent projection, this also affects the <code>!is.null(ynew)</code> case (see below). The scale on which the predictions are returned, either "link" or "response" (see <code>predict.glm()</code> but note that <code>predict.refmodel()</code> does not adhere to the typical R convention of a default prediction on link scale). For both scales, the predictions are averaged across the posterior draws. In case of the latent projection, argument <code>type</code> is similar in spirit to argument <code>resp_oscale</code> from other functions: If (i) <code>is.null(ynew)</code> , then argument <code>type</code> affects the predictions as described above. In that case, note that <code>type = "link"</code> yields the linear predictors without any modifications that may be due to the original response distribution (e.g., for a <code>brms::cumulative()</code> model, the ordered thresholds are not taken into account). If (ii) <code>!is.null(ynew)</code> , then argument <code>type</code> also affects the scale of the log posterior predictive densities (<code>type = "response"</code> for the original response scale, <code>type = "link"</code> for the latent Gaussian scale).
...	Currently ignored.

Details

Argument `weightsnew` is only relevant if `!is.null(ynew)`.

In case of a multilevel reference model, group-level effects for new group levels are drawn randomly from a (multivariate) Gaussian distribution. When setting `projpred.mlvl_pred_new` to `TRUE`, all group levels from `newdata` (even those that already exist in the original dataset) are treated as new group levels (if `is.null(newdata)`, all group levels from the original dataset are considered as new group levels in that case).

Value

In the following, N , C_{cat} , and C_{lat} from help topic [refmodel-init-get](#) are used. Furthermore, let C denote either C_{cat} (if `type = "response"`) or C_{lat} (if `type = "link"`). Then, if `is.null(ynew)`, the returned object contains the reference model's predictions (with the scale depending on argument `type`) as:

- a length- N vector in case of (i) the traditional projection, (ii) the latent projection with `type = "link"`, or (iii) the latent projection with `type = "response"` and `object$family$cats` being `NULL`;
- an $N \times C$ matrix in case of (i) the augmented-data projection or (ii) the latent projection with `type = "response"` and `object$family$cats` being not `NULL`.

If `!is.null(ynew)`, the returned object is a length- N vector of log posterior predictive densities evaluated at `ynew`.

predictor_terms	<i>Predictor terms used in a project() run</i>
-----------------	--

Description

For a projection object (returned by [project\(\)](#), possibly as elements of a list), this function extracts the combination of predictor terms onto which the projection was performed.

Usage

```
predictor_terms(object, ...)

## S3 method for class 'projection'
predictor_terms(object, ...)
```

Arguments

object	An object of class <code>projection</code> (returned by project() , possibly as elements of a list) from which to retrieve the predictor terms.
...	Currently ignored.

Value

A character vector of predictor terms.

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
```

```
# example; this is not recommended in general):
fit <- rstanarm::stan_glm(
  y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
  QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
)

# Projection onto an arbitrary combination of predictor terms (with a small
# value for `nclusters`, but only for the sake of speed in this example;
# this is not recommended in general):
prj <- project(fit, solution_terms = c("X1", "X3", "X5"), nclusters = 10,
  seed = 9182)
print(predictor_terms(prj)) # gives `c("X1", "X3", "X5")`
}
```

print.vsel

Print results (summary) of a `varsel()` or `cv_varsel()` run

Description

This is the `print()` method for `vsel` objects (returned by `varsel()` or `cv_varsel()`). It displays a summary of a `varsel()` or `cv_varsel()` run by first calling `summary.vsel()` and then `print.vselsummary()`.

Usage

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

Arguments

<code>x</code>	An object of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>).
<code>...</code>	Arguments passed to <code>summary.vsel()</code> (apart from argument <code>digits</code> which is passed to <code>print.vselsummary()</code>).

Value

The output of `summary.vsel()` (invisible).

print.vselsummary	Print summary of a <code>varsel()</code> or <code>cv_varsel()</code> run
-------------------	--

Description

This is the `print()` method for summary objects created by `summary.vsel()`. It displays a summary of the results from a `varsel()` or `cv_varsel()` run.

Usage

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

Arguments

<code>x</code>	An object of class <code>vselsummary</code> .
<code>...</code>	Arguments passed to <code>print.data.frame()</code> .

Details

In the table printed at the bottom, column `solution_terms` contains the full-data predictor ranking and column `cv_proportions_diag` contains the main diagonal of the matrix returned by `cv_proportions()` (with `cumulate` as set in the `summary.vsel()` call that created `x`).

Value

The output of `summary.vsel()` (invisible).

project	Projection onto submodel(s)
---------	-----------------------------

Description

Project the posterior of the reference model onto the parameter space of a single submodel consisting of a specific combination of predictor terms or (after variable selection) onto the parameter space of a single or multiple submodels of specific sizes.

Usage

```
project(
  object,
  nterms = NULL,
  solution_terms = NULL,
  refit_prj = TRUE,
  ndraws = 400,
```

```

nclusters = NULL,
seed = NA,
regul = 1e-04,
...
)

```

Arguments

object	An object which can be used as input to <code>get_refmodel()</code> (in particular, objects of class <code>refmodel</code>).
nterms	Only relevant if object is of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>). Ignored if <code>!is.null(solution_terms)</code> . Number of terms for the submodel (the corresponding combination of predictor terms is taken from object). If a numeric vector, then the projection is performed for each element of this vector. If <code>NULL</code> (and <code>is.null(solution_terms)</code>), then the value suggested by <code>suggest_size()</code> is taken (with default arguments for <code>suggest_size()</code> , implying that this suggested size is based on the ELPD). Note that <code>nterms</code> does not count the intercept, so use <code>nterms = 0</code> for the intercept-only model.
solution_terms	If not <code>NULL</code> , then this needs to be a character vector of predictor terms for the submodel onto which the projection will be performed. Argument <code>nterms</code> is ignored in that case. For an object which is not of class <code>vsel</code> , <code>solution_terms</code> must not be <code>NULL</code> .
refit_prj	A single logical value indicating whether to fit the submodels (again) (<code>TRUE</code>) or to retrieve the fitted submodels from object (<code>FALSE</code>). For an object which is not of class <code>vsel</code> , <code>refit_prj</code> must be <code>TRUE</code> . Note that currently, <code>refit_prj = FALSE</code> requires some caution, see GitHub issue #168.
ndraws	Only relevant if <code>refit_prj</code> is <code>TRUE</code> . Number of posterior draws to be projected. Ignored if <code>nclusters</code> is not <code>NULL</code> or if the reference model is of class <code>datafit</code> (in which case one cluster is used). If both (<code>nclusters</code> and <code>ndraws</code>) are <code>NULL</code> , the number of posterior draws from the reference model is used for <code>ndraws</code> . See also section "Details" below.
nclusters	Only relevant if <code>refit_prj</code> is <code>TRUE</code> . Number of clusters of posterior draws to be projected. Ignored if the reference model is of class <code>datafit</code> (in which case one cluster is used). For the meaning of <code>NULL</code> , see argument <code>ndraws</code> . See also section "Details" below.
seed	Pseudorandom number generation (PRNG) seed by which the same results can be obtained again if needed. Passed to argument <code>seed</code> of <code>set.seed()</code> , but can also be <code>NA</code> to not call <code>set.seed()</code> at all. If not <code>NA</code> , then the PRNG state is reset (to the state before calling <code>project()</code>) upon exiting <code>project()</code> . Here, <code>seed</code> is used for clustering the reference model's posterior draws (if <code>!is.null(nclusters)</code>) and for drawing new group-level effects when predicting from a multilevel submodel (however, not yet in case of a GAMM) and having global option <code>projpred.mlvl_pred_new</code> set to <code>TRUE</code> . (Such a prediction takes place when calculating output elements <code>dis</code> and <code>ce</code> .)
regul	A number giving the amount of ridge regularization when projecting onto (i.e., fitting) submodels which are GLMs. Usually there is no need for regularization, but sometimes we need to add some regularization to avoid numerical problems.

... Arguments passed to `get_refmodel()` (if `get_refmodel()` is actually used; see argument object) as well as to the divergence minimizer (if `refit_prj` is TRUE).

Details

Arguments `ndraws` and `nclusters` are automatically truncated at the number of posterior draws in the reference model (which is 1 for `datafits`). Using less draws or clusters in `ndraws` or `nclusters` than posterior draws in the reference model may result in slightly inaccurate projection performance. Increasing these arguments affects the computation time linearly.

Note that if `project()` is applied to output from `cv_varsel()`, then `refit_prj = FALSE` will take the results from the *full-data* search.

Value

If the projection is performed onto a single submodel (i.e., `length(terms) == 1` || `!is.null(solution_terms)`), an object of class `projection` which is a list containing the following elements:

`dis` Projected draws for the dispersion parameter.

`ce` The cross-entropy part of the Kullback-Leibler (KL) divergence from the reference model to the submodel. For some families, this is not the actual cross-entropy, but a reduced one where terms which would cancel out when calculating the KL divergence have been dropped. In case of the Gaussian family, that reduced cross-entropy is further modified, yielding merely a proxy.

`wdraws_prj` Weights for the projected draws.

`solution_terms` A character vector of the submodel's predictor terms.

`outdmin` A list containing the submodel fits (one fit per projected draw). This is the same as the return value of the `div_minimizer` function (see `init_refmodel()`), except if `project()` was used with an object of class `vsel` based on an L1 search as well as with `refit_prj = FALSE`, in which case this is the output from an internal *L1-penalized* divergence minimizer.

`cl_ref` A numeric vector of length equal to the number of posterior draws in the reference model, containing the cluster indices of these draws.

`wdraws_ref` A numeric vector of length equal to the number of posterior draws in the reference model, giving the weights of these draws. These weights should be treated as not being normalized (i.e., they don't necessarily sum to 1).

`p_type` A single logical value indicating whether the reference model's posterior draws have been clustered for the projection (TRUE) or not (FALSE).

`refmodel` The reference model object.

If the projection is performed onto more than one submodel, the output from above is returned for each submodel, giving a list with one element for each submodel.

The elements of an object of class `projection` are not meant to be accessed directly but instead via helper functions (see the main vignette and [projpred-package](#)). An exception is element `wdraws_prj` which is currently needed to weight quantities derived from the projected draws in case of clustered projection, e.g., after applying `as.matrix.projection()` (which throws a warning in case of clustered projection to make users aware of this problem).

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Run varsel() (here without cross-validation and with small values for
  # `nterms_max`, `nclusters`, and `nclusters_pred`, but only for the sake of
  # speed in this example; this is not recommended in general):
  vs <- varsel(fit, nterms_max = 3, nclusters = 5, nclusters_pred = 10,
    seed = 5555)

  # Projection onto the best submodel with 2 predictor terms (with a small
  # value for `nclusters`, but only for the sake of speed in this example;
  # this is not recommended in general):
  prj_from_vs <- project(vs, nterms = 2, nclusters = 10, seed = 9182)

  # Projection onto an arbitrary combination of predictor terms (with a small
  # value for `nclusters`, but only for the sake of speed in this example;
  # this is not recommended in general):
  prj <- project(fit, solution_terms = c("X1", "X3", "X5"), nclusters = 10,
    seed = 9182)
}
```

ranking

Predictor ranking(s)

Description

Extracts the *predictor ranking(s)* from an object of class `vsel` (returned by `varsel()` or `cv_varsel()`). A predictor ranking is simply a character vector of predictor terms ranked by predictive relevance (with the most relevant term first). In any case, objects of class `vsel` contain the predictor ranking based on the *full-data* search. If an object of class `vsel` is based on a cross-validation (CV) with fold-wise searches (i.e., if it was created by `cv_varsel()` with `validate_search = TRUE`), then it also contains *fold-wise* predictor rankings.

Usage

```
ranking(object, ...)

## S3 method for class 'vsel'
ranking(object, nterms_max = NULL, ...)
```


Arguments

object	The object from which to retrieve the predictor ranking(s). Possible classes may be inferred from the names of the corresponding methods (see also the description).
...	Currently ignored.
nterms_max	Maximum submodel size (number of predictor terms) for the predictor ranking(s), i.e., the submodel size at which to cut off the predictor ranking(s). Using NULL is effectively the same as setting nterms_max to the full model size, i.e., this means to not cut off the predictor ranking(s) at all. Note that nterms_max does not count the intercept, so nterms_max = 1 corresponds to the submodel consisting of the first (non-intercept) predictor term.

Value

An object of class `ranking` which is a list with the following elements:

- `fulldata`: The predictor ranking from the full-data search.
- `foldwise`: The predictor rankings from the fold-wise searches in the form of a character matrix (only available if object is based on a CV with fold-wise searches, otherwise element `foldwise` is NULL). The rows of this matrix correspond to the CV folds and the columns to the submodel sizes. Each row contains the predictor ranking from the search of that CV fold.

See Also

[cv_proportions\(\)](#)

Examples

```
# For an example, see `?plot.cv_proportions`.
```

refmodel-init-get

Reference model and more general information

Description

Function `get_refmodel()` is a generic function whose methods usually call `init_refmodel()` which is the underlying workhorse (and may also be used directly without a call to `get_refmodel()`).

Both, `get_refmodel()` and `init_refmodel()`, create an object containing information needed for the projection predictive variable selection, namely about the reference model, the submodels, and how the projection should be carried out. For the sake of simplicity, the documentation may refer to the resulting object also as "reference model" or "reference model object", even though it also contains information about the submodels and the projection.

A "typical" reference model object is created by `get_refmodel.stanreg()` and `brms::get_refmodel.brmsfit()`, either implicitly by a call to a top-level function such as `project()`, `varsel()`, and `cv_varsel()`

or explicitly by a call to `get_refmodel()`. All non-"typical" reference model objects will be called "custom" reference model objects.

Some arguments are for K -fold cross-validation (K -fold CV) only; see `cv_varsel()` for the use of K -fold CV in **projpred**.

Usage

```
get_refmodel(object, ...)

## S3 method for class 'refmodel'
get_refmodel(object, ...)

## S3 method for class 'vsel'
get_refmodel(object, ...)

## Default S3 method:
get_refmodel(object, formula, family = NULL, ...)

## S3 method for class 'stanreg'
get_refmodel(object, latent = FALSE, dis = NULL, ...)

init_refmodel(
  object,
  data,
  formula,
  family,
  ref_predfun = NULL,
  div_minimizer = NULL,
  proj_predfun = NULL,
  extract_model_data,
  cvfun = NULL,
  cvfits = NULL,
  dis = NULL,
  cvrefbuilder = NULL,
  ...
)
```

Arguments

object	For <code>init_refmodel()</code> , an object that the functions from arguments <code>extract_model_data</code> and <code>ref_predfun</code> can be applied to, with a <code>NULL</code> object being treated specially (see section "Value" below). For <code>get_refmodel.default()</code> , an object of type list that (i) function <code>family()</code> can be applied to in order to retrieve the family (if argument <code>family</code> is <code>NULL</code>) and (ii) has an element called <code>data</code> containing the original dataset (see argument <code>data</code> of <code>init_refmodel()</code>), additionally to the properties required for <code>init_refmodel()</code> . For non-default methods of <code>get_refmodel()</code> , an object of the corresponding class.
...	For <code>get_refmodel.default()</code> and <code>get_refmodel.stanreg()</code> : arguments passed to <code>init_refmodel()</code> . For the <code>get_refmodel()</code> generic: arguments passed to

	the appropriate method. For <code>init_refmodel()</code> : arguments passed to <code>extend_family()</code> (apart from family).
formula	The full formula to use for the search procedure. For custom reference models, this does not necessarily coincide with the reference model's formula. For general information about formulas in R, see <code>formula</code> . For information about possible right-hand side (i.e., predictor) terms in formula here, see the main vignette and section "Formula terms" below. For multilevel formulas, see also package lme4 (in particular, functions <code>lme4::lmer()</code> and <code>lme4::glmer()</code>). For additive formulas, see also packages mgcv (in particular, function <code>mgcv::gam()</code>) and gamm4 (in particular, function <code>gamm4::gamm4()</code>).
family	An object of class family representing the observation model (i.e., the distributional family for the response) of the <i>submodels</i> . (However, the link and the inverse-link function of this family are also used for quantities like predictions and fitted values related to the <i>reference model</i> .) May be NULL for <code>get_refmodel.default()</code> in which case the family is retrieved from object. For custom reference models, family does not have to coincide with the family of the reference model (if the reference model possesses a formal family at all). In typical reference models, however, these families do coincide.
latent	A single logical value indicating whether to use the latent projection (TRUE) or not (FALSE). Note that setting latent = TRUE causes all arguments starting with <code>augdat_</code> to be ignored.
dis	A vector of posterior draws for the reference model's dispersion parameter or—more precisely—the posterior values for the reference model's parameter-conditional predictive variance (assuming that this variance is the same for all observations). May be NULL if the submodels have no dispersion parameter or if the submodels do have a dispersion parameter, but object is NULL (in which case 0 is used for dis). Note that for the <code>gaussian()</code> family, dis is the standard deviation, not the variance.
data	A data.frame containing the data to use for the projection predictive variable selection. Any contrasts attributes of the dataset's columns are silently removed. For custom reference models, the columns of data do not necessarily have to coincide with those of the dataset used for fitting the reference model, but keep in mind that a row-subset of data is used for argument <code>newdata</code> of <code>ref_predfun</code> during <i>K</i> -fold CV.
ref_predfun	Prediction function for the linear predictor of the reference model, including offsets (if existing). See also section "Arguments ref_predfun, proj_predfun, and div_minimizer" below. If object is NULL, ref_predfun is ignored and an internal default is used instead.
div_minimizer	A function for minimizing the Kullback-Leibler (KL) divergence from the reference model to a submodel (i.e., for performing the projection of the reference model onto a submodel). The output of <code>div_minimizer</code> is used, e.g., by <code>proj_predfun</code> 's argument <code>fits</code> . See also section "Arguments ref_predfun, proj_predfun, and div_minimizer" below.
proj_predfun	Prediction function for the linear predictor of a submodel onto which the reference model is projected. See also section "Arguments ref_predfun, proj_predfun, and div_minimizer" below.

extract_model_data	A function for fetching some variables (response, observation weights, offsets) from the original dataset (supplied to argument data) or from a new dataset. See also section "Argument extract_model_data" below.
cvfun	For K -fold CV only. A function that, given a fold indices vector, fits the reference model separately for each fold and returns the K model fits as a list. Each of the K model fits needs to be a list. If object is NULL, cvfun may be NULL for using an internal default. Only one of cvfits and cvfun needs to be provided (for K -fold CV). Note that cvfits takes precedence over cvfun, i.e., if both are provided, cvfits is used.
cvfits	For K -fold CV only. A list containing a sub-list called fits containing the K model fits from which reference model structures are created. The cvfits list (i.e., the super-list) needs to have attributes K and folds: K has to be a single integer giving the number of folds and folds has to be an integer vector giving the fold indices (one fold index per observation). Each element of cvfits\$fits (i.e., each of the K model fits) needs to be a list. Only one of cvfits and cvfun needs to be provided (for K -fold CV). Note that cvfits takes precedence over cvfun, i.e., if both are provided, cvfits is used.
cvrefbuilder	For K -fold CV only. A function that, given a reference model fit for fold $k \in \{1, \dots, K\}$ (this model fit is the k -th element of the return value of cvfun or the k -th element of cvfits\$fits, extended by elements omitted (containing the indices of the left-out observations in that fold) and projpred_k (containing the integer k)), returns an object of the same type as <code>init_refmodel()</code> does. Argument cvrefbuilder may be NULL for using an internal default: <code>get_refmodel()</code> if object is not NULL and a function calling <code>init_refmodel()</code> appropriately (with the assumption <code>dis = 0</code>) if object is NULL.

Value

An object that can be passed to all the functions that take the reference model fit as the first argument, such as `varsel()`, `cv_varsel()`, `project()`, `proj_linpred()`, and `proj_predict()`. Usually, the returned object is of class `refmodel`. However, if object is NULL, the returned object is of class `datafit` as well as of class `refmodel` (with `datafit` being first). Objects of class `datafit` are handled differently at several places throughout this package.

The elements of the returned object are not meant to be accessed directly but instead via downstream functions (see the functions mentioned above as well as `predict.refmodel()`).

Formula terms

Although bad practice (in general), a reference model lacking an intercept can be used within **projpred**. However, it will always be projected onto submodels which *include* an intercept. The reason is that even if the true intercept in the reference model is zero, this does not need to hold for the submodels.

In multilevel (group-level) terms, function calls on the right-hand side of the `|` character (e.g., `(1 | gr(group_variable))`), which is possible in **brms** are currently not allowed in **projpred**.

For additive models (still an experimental feature), only `mgcv::s()` and `mgcv::t2()` are currently supported as smooth terms. Furthermore, these need to be called without any arguments apart from

the predictor names (symbols). For example, for smoothing the effect of a predictor x , only $s(x)$ or $t2(x)$ are allowed. As another example, for smoothing the joint effect of two predictors x and z , only $s(x, z)$ or $t2(x, z)$ are allowed (and analogously for higher-order joint effects, e.g., of three predictors). Note that all smooth terms need to be included in formula (there is no random argument as in `rstanarm::stan_gamm4()`, for example).

Arguments `ref_predfun`, `proj_predfun`, and `div_minimizer`

Arguments `ref_predfun`, `proj_predfun`, and `div_minimizer` may be NULL for using an internal default (see [projpred-package](#) for the functions used by the default divergence minimizers). Otherwise, let N denote the number of observations (in case of CV, these may be reduced to each fold), S_{ref} the number of posterior draws for the reference model's parameters, and S_{prj} the number of draws for the parameters of a submodel that the reference model has been projected onto (short: the number of projected draws). For the augmented-data projection, let C_{cat} denote the number of response categories, C_{lat} the number of latent response categories (which typically equals $C_{\text{cat}} - 1$), and define $N_{\text{augcat}} := N \cdot C_{\text{cat}}$ as well as $N_{\text{auglat}} := N \cdot C_{\text{lat}}$. Then the functions supplied to these arguments need to have the following prototypes:

- `ref_predfun`: `ref_predfun(fit, newdata = NULL)` where:
 - `fit` accepts the reference model fit as given in argument object (but possibly re-fitted to a subset of the observations, as done in K -fold CV).
 - `newdata` accepts either NULL (for using the original dataset, typically stored in `fit`) or data for new observations (at least in the form of a `data.frame`).
- `proj_predfun`: `proj_predfun(fits, newdata)` where:
 - `fits` accepts a list of length S_{prj} containing this number of submodel fits. This list is the same as that returned by `project()` in its output element `outdmin` (which in turn is the same as the return value of `div_minimizer`, except if `project()` was used with an object of class `vsel` based on an L1 search as well as with `refit_prj = FALSE`).
 - `newdata` accepts data for new observations (at least in the form of a `data.frame`).
- `div_minimizer` does not need to have a specific prototype, but it needs to be able to be called with the following arguments:
 - `formula` accepts either a standard `formula` with a single response (if $S_{\text{prj}} = 1$ or in case of the augmented-data projection) or a `formula` with $S_{\text{prj}} > 1$ response variables `cbind()`-ed on the left-hand side in which case the projection has to be performed for each of the response variables separately.
 - `data` accepts a `data.frame` to be used for the projection. In case of the traditional or the latent projection, this dataset has N rows. In case of the augmented-data projection, this dataset has N_{augcat} rows.
 - `family` accepts an object of class `family`.
 - `weights` accepts either observation weights (at least in the form of a numeric vector) or NULL (for using a vector of ones as weights).
 - `projpred_var` accepts an $N \times S_{\text{prj}}$ matrix of predictive variances (necessary for **projpred**'s internal GLM fitter) in case of the traditional or the latent projection and an $N_{\text{augcat}} \times S_{\text{prj}}$ matrix (containing only NAs) in case of the augmented-data projection.
 - `projpred_regul` accepts a single numeric value as supplied to argument `regul` of `project()`, for example.

- `projpred_ws_aug` accepts an $N \times S_{\text{prj}}$ matrix of expected values for the response in case of the traditional or the latent projection and an $N_{\text{augcat}} \times S_{\text{prj}}$ matrix of probabilities for the response categories in case of the augmented-data projection.
- ... accepts further arguments specified by the user.

The return value of these functions needs to be:

- `ref_predfun`: for the traditional or the latent projection, an $N \times S_{\text{ref}}$ matrix; for the augmented-data projection, an $S_{\text{ref}} \times N \times C_{\text{lat}}$ array (the only exception is the augmented-data projection for the `binomial()` family in which case `ref_predfun` needs to return an $N \times S_{\text{ref}}$ matrix just like for the traditional projection because the array is constructed by an internal wrapper function).
- `proj_predfun`: for the traditional or the latent projection, an $N \times S_{\text{prj}}$ matrix; for the augmented-data projection, an $N \times C_{\text{lat}} \times S_{\text{prj}}$ array.
- `div_minimizer`: a list of length S_{prj} containing this number of submodel fits.

Argument `extract_model_data`

The function supplied to argument `extract_model_data` needs to have the prototype

```
extract_model_data(object, newdata, wrhs = NULL, orhs = NULL,
                  extract_y = TRUE)
```

where:

- `object` accepts the reference model fit as given in argument `object` (but possibly re-fitted to a subset of the observations, as done in K -fold CV).
- `newdata` accepts either `NULL` (for using the original dataset, typically stored in `object`) or data for new observations (at least in the form of a `data.frame`).
- `wrhs` accepts at least either `NULL` (for using a vector of ones) or a right-hand side formula consisting only of the variable in `newdata` containing the weights.
- `orhs` accepts at least either `NULL` (for using a vector of zeros) or a right-hand side formula consisting only of the variable in `newdata` containing the offsets.
- `extract_y` accepts a single logical value indicating whether output element `y` (see below) shall be `NULL` (`TRUE`) or not (`FALSE`).

The return value of `extract_model_data` needs to be a list with elements `y`, `weights`, and `offset`, each being a numeric vector containing the data for the response, the observation weights, and the offsets, respectively. An exception is that `y` may also be `NULL` (depending on argument `extract_y`), a non-numeric vector, or a factor.

The weights and offsets returned by `extract_model_data` will be assumed to hold for the reference model as well as for the submodels.

Augmented-data projection

If a custom reference model for an augmented-data projection is needed, see also `extend_family()`.

For the augmented-data projection, the response vector resulting from `extract_model_data` is internally coerced to a factor (using `as.factor()`). The levels of this factor have to be identical to `family$cats` (*after* applying `extend_family()` internally; see `extend_family()`'s argument `augdat_y_unqs`).

Note that response-specific offsets (i.e., one length- N offset vector per response category) are not supported by **projpred** yet. So far, only offsets which are the same across all response categories are supported. This is why in case of the `brms::categorical()` family, offsets are currently not supported at all.

Currently, `object = NULL` (i.e., a `datafit`; see section "Value") is not supported in case of the augmented-data projection.

Latent projection

If a custom reference model for a latent projection is needed, see also `extend_family()`.

For the latent projection, `family$cats` (*after* applying `extend_family()` internally; see `extend_family()`'s argument `latent_y_unqs`) currently must not be `NULL` if the original (i.e., non-latent) response is a factor. Conversely, if `family$cats` (*after* applying `extend_family()`) is non-`NULL`, the response vector resulting from `extract_model_data` is internally coerced to a factor (using `as.factor()`). The levels of this factor have to be identical to that non-`NULL` element `family$cats`.

Currently, `object = NULL` (i.e., a `datafit`; see section "Value") is not supported in case of the latent projection.

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Define the reference model explicitly:
  ref <- get_refmodel(fit)
  print(class(ref)) # gives `"refmodel"`
  # Now see, for example, `?varsel`, `?cv_varsel`, and `?project` for
  # possible post-processing functions. Most of the post-processing functions
  # call get_refmodel() internally at the beginning, so you will rarely need
  # to call get_refmodel() yourself.

  # A custom reference model which may be used in a variable selection where
  # the candidate predictors are not a subset of those used for the reference
  # model's predictions:
}
```

```

ref_cust <- init_refmodel(
  fit,
  data = dat_gauss,
  formula = y ~ X6 + X7,
  family = gaussian(),
  extract_model_data = function(object, newdata = NULL, wrhs = NULL,
                                orhs = NULL, extract_y = TRUE) {
    if (!extract_y) {
      resp_form <- NULL
    } else {
      resp_form <- ~ y
    }

    if (is.null(newdata)) {
      newdata <- dat_gauss
    }

    args <- projpred::nlist(object, newdata, wrhs, orhs, resp_form)
    return(projpred::do_call(projpred:::.extract_model_data, args))
  },
  cvfun = function(folds) {
    kfold(
      fit, K = max(folds), save_fits = TRUE, folds = folds, cores = 1
    )$fits[, "fit"]
  },
  dis = as.matrix(fit)[, "sigma"]
)
# Now, the post-processing functions mentioned above (for example,
# varsel(), cv_varsel(), and project()) may be applied to `ref_cust`.
}

```

solution_terms

Retrieve the full-data solution path from a `varsel()` or `cv_varsel()` run or the predictor combination from a `project()` run

Description

The `solution_terms.vsel()` method retrieves the solution path from a full-data search (`vsel` objects are returned by `varsel()` or `cv_varsel()`). The `solution_terms.projection()` method retrieves the predictor combination onto which a projection was performed (projection objects are returned by `project()`, possibly as elements of a list). Both methods (and hence also the `solution_terms()` generic) are deprecated and will be removed in a future release. Please use `ranking()` instead of `solution_terms.vsel()` (`ranking()`'s output element `fulldata` contains the full-data predictor ranking that is extracted by `solution_terms.vsel()`; `ranking()`'s output element `foldwise` contains the fold-wise predictor rankings—if available—which were previously not accessible via a built-in function) and `predictor_terms()` instead of `solution_terms.projection()`.

Usage

```
solution_terms(object, ...)

## S3 method for class 'vsel'
solution_terms(object, ...)

## S3 method for class 'projection'
solution_terms(object, ...)
```

Arguments

object	The object from which to retrieve the predictor terms. Possible classes may be inferred from the names of the corresponding methods (see also the description).
...	Currently ignored.

Value

A character vector of predictor terms.

suggest_size	<i>Suggest submodel size</i>
--------------	------------------------------

Description

This function can suggest an appropriate submodel size based on a decision rule described in section "Details" below. Note that this decision is quite heuristic and should be interpreted with caution. It is recommended to examine the results via [plot.vsel\(\)](#) and/or [summary.vsel\(\)](#) and to make the final decision based on what is most appropriate for the problem at hand.

Usage

```
suggest_size(object, ...)

## S3 method for class 'vsel'
suggest_size(
  object,
  stat = "elpd",
  pct = 0,
  type = "upper",
  thres_elpd = NA,
  warnings = TRUE,
  ...
)
```

Arguments

object	An object of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>).
...	Arguments passed to <code>summary.vsel()</code> , except for <code>object</code> , <code>stats</code> (which is set to <code>stat</code>), <code>type</code> , and <code>deltas</code> (which is set to <code>TRUE</code>). See section "Details" below for some important arguments which may be passed here.
stat	Performance statistic (i.e., utility or loss) used for the decision. See argument <code>stats</code> of <code>summary.vsel()</code> for possible choices.
pct	A number giving the proportion (<i>not</i> percents) of the <i>relative</i> null model utility one is willing to sacrifice. See section "Details" below for more information.
type	Either "upper" or "lower" determining whether the decision is based on the upper or lower confidence interval bound, respectively. See section "Details" below for more information.
thres_elpd	Only relevant if <code>stat %in% c("elpd", "mlpd")</code> . The threshold for the ELPD difference (taking the submodel's ELPD minus the baseline model's ELPD) above which the submodel's ELPD is considered to be close enough to the baseline model's ELPD. An equivalent rule is applied in case of the MLPD. See section "Details" for a formalization. Supplying <code>NA</code> deactivates this.
warnings	Mainly for internal use. A single logical value indicating whether to throw warnings if automatic suggestion fails. Usually there is no reason to set this to <code>FALSE</code> .

Details

In general (beware of special extensions below), the suggested model size is the smallest model size $j \in \{0, 1, \dots, \text{nterms_max}\}$ for which either the lower or upper bound (depending on argument `type`) of the normal-approximation (or bootstrap; see argument `stat`) confidence interval (with nominal coverage $1 - \alpha$; see argument `alpha` of `summary.vsel()`) for $U_j - U_{\text{base}}$ (with U_j denoting the j -th submodel's true utility and U_{base} denoting the baseline model's true utility) falls above (or is equal to)

$$\text{pct} \cdot (u_0 - u_{\text{base}})$$

where u_0 denotes the null model's estimated utility and u_{base} the baseline model's estimated utility. The baseline model is either the reference model or the best submodel found (see argument `baseline` of `summary.vsel()`).

If `!is.na(thres_elpd)` and `stat = "elpd"`, the decision rule above is extended: The suggested model size is then the smallest model size j fulfilling the rule above *or* $u_j - u_{\text{base}} > \text{thres_elpd}$. Correspondingly, in case of `stat = "mlpd"` (and `!is.na(thres_elpd)`), the suggested model size is the smallest model size j fulfilling the rule above *or* $u_j - u_{\text{base}} > \frac{\text{thres_elpd}}{N}$ with N denoting the number of observations.

For example (disregarding the special extensions in case of `!is.na(thres_elpd)` with `stat = "elpd"` or `stat = "mlpd"`), `alpha = 2 * pnorm(-1)`, `pct = 0`, and `type = "upper"` means that we select the smallest model size for which the upper bound of the $1 - 2 * \text{pnorm}(-1)$ (approximately 68.3%) confidence interval for $U_j - U_{\text{base}}$ exceeds (or is equal to) zero, that is (if `stat` is a performance statistic for which the normal approximation is used, not the bootstrap), for which the submodel's utility estimate is at most one standard error smaller than the baseline model's utility estimate (with that standard error referring to the utility *difference*).

Apart from the two `summary.vsel()` arguments mentioned above (`alpha` and `baseline`), `resp_oscale` is another important `summary.vsel()` argument that may be passed via `...`

Value

A single numeric value, giving the suggested submodel size (or NA if the suggestion failed).

The intercept is not counted by `suggest_size()`, so a suggested size of zero stands for the intercept-only model.

Note

Loss statistics like the root mean squared error (RMSE) and the mean squared error (MSE) are converted to utilities by multiplying them by -1, so a call such as `suggest_size(object, stat = "rmse", type = "upper")` finds the smallest model size whose upper confidence interval bound for the *negative* RMSE or MSE exceeds the cutoff (or, equivalently, has the lower confidence interval bound for the RMSE or MSE below the cutoff). This is done to make the interpretation of argument `type` the same regardless of argument `stat`.

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Run varsel() (here without cross-validation and with small values for
  # `nterms_max`, `nclusters`, and `nclusters_pred`, but only for the sake of
  # speed in this example; this is not recommended in general):
  vs <- varsel(fit, nterms_max = 3, nclusters = 5, nclusters_pred = 10,
    seed = 5555)
  print(suggest_size(vs))
}
```

summary.vsel

Summary of a `varsel()` or `cv_varsel()` run**Description**

This is the `summary()` method for `vsel` objects (returned by `varsel()` or `cv_varsel()`). Apart from some general information about the `varsel()` or `cv_varsel()` run, it shows the full-data predictor ranking, basic information about the (CV) variability in the ranking of the predictors (if available; inferred from `cv_proportions()`), and estimates for user-specified predictive performance statistics. For a graphical representation, see `plot.vsel()`.

Usage

```
## S3 method for class 'vsel'
summary(
  object,
  nterms_max = NULL,
  stats = "elpd",
  type = c("mean", "se", "diff", "diff.se"),
  deltas = FALSE,
  alpha = 2 * pnorm(-1),
  baseline = if (!inherits(object$refmodel, "datafit")) "ref" else "best",
  resp_oscale = TRUE,
  cumulate = FALSE,
  ...
)
```

Arguments

object	An object of class <code>vsel</code> (returned by <code>varsel()</code> or <code>cv_varsel()</code>).
nterms_max	Maximum submodel size (number of predictor terms) for which the performance statistics are calculated. Using <code>NULL</code> is effectively the same as <code>length(ranking(object)[["fulldata"]])</code> . Note that <code>nterms_max</code> does not count the intercept, so use <code>nterms_max = 0</code> for the intercept-only model. For <code>plot.vsel()</code> , <code>nterms_max</code> must be at least 1.
stats	<p>One or more character strings determining which performance statistics (i.e., utilities or losses) to estimate based on the observations in the evaluation (or "test") set (in case of cross-validation, these are all observations because they are partitioned into multiple test sets; in case of <code>varsel()</code> with <code>d_test = NULL</code>, these are again all observations because the test set is the same as the training set). Available statistics are:</p> <ul style="list-style-type: none"> • <code>"elpd"</code>: expected log (pointwise) predictive density (for a new dataset). Estimated by the sum of the observation-specific log predictive density values (with each of these predictive density values being a—possibly weighted—average across the parameter draws). • <code>"m1pd"</code>: mean log predictive density, that is, <code>"elpd"</code> divided by the number of observations. • <code>"mse"</code>: mean squared error (only available in the situations mentioned in section "Details" below). • <code>"rmse"</code>: root mean squared error (only available in the situations mentioned in section "Details" below). For the corresponding standard error and lower and upper confidence interval bounds, bootstrapping is used. • <code>"acc"</code> (or its alias, <code>"pctcorr"</code>): classification accuracy (only available in the situations mentioned in section "Details" below). • <code>"auc"</code>: area under the ROC curve (only available in the situations mentioned in section "Details" below). For the corresponding standard error and lower and upper confidence interval bounds, bootstrapping is used.
type	One or more items from <code>"mean"</code> , <code>"se"</code> , <code>"lower"</code> , <code>"upper"</code> , <code>"diff"</code> , and <code>"diff.se"</code> indicating which of these to compute for each item from <code>stats</code> (mean, standard

	error, lower and upper confidence interval bounds, mean difference to the corresponding statistic of the reference model, and standard error of this difference, respectively). The confidence interval bounds belong to normal-approximation (or bootstrap; see argument stats) confidence intervals with (nominal) coverage $1 - \alpha$. Items "diff" and "diff.se" are only supported if deltas is FALSE.
deltas	If TRUE, the submodel statistics are estimated as differences from the baseline model (see argument baseline). With a "difference <i>from</i> the baseline model", we mean to take the submodel statistic minus the baseline model statistic (not the other way round).
alpha	A number determining the (nominal) coverage $1 - \alpha$ of the normal-approximation (or bootstrap; see argument stats) confidence intervals. For example, in case of the normal approximation, $\alpha = 2 * pnorm(-1)$ corresponds to a confidence interval stretching by one standard error on either side of the point estimate.
baseline	For <code>summary.vsel()</code> : Only relevant if deltas is TRUE. For <code>plot.vsel()</code> : Always relevant. Either "ref" or "best", indicating whether the baseline is the reference model or the best submodel found (in terms of stats[1]), respectively.
resp_oscale	Only relevant for the latent projection. A single logical value indicating whether to calculate the performance statistics on the original response scale (TRUE) or on latent scale (FALSE).
cumulate	Passed to argument cumulate of <code>cv_proportions()</code> . Affects column cv_proportions_diag of the summary table.
...	Arguments passed to the internal function which is used for bootstrapping (if applicable; see argument stats). Currently, relevant arguments are B (the number of bootstrap samples, defaulting to 2000) and seed (see <code>set.seed()</code> , but defaulting to NA so that <code>set.seed()</code> is not called within that function at all).

Details

The stats options "mse" and "rmse" are only available for:

- the traditional projection,
- the latent projection with `resp_oscale = FALSE`,
- the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being NULL.

The stats option "acc" (= "pctcorr") is only available for:

- the `binomial()` family in case of the traditional projection,
- all families in case of the augmented-data projection,
- the `binomial()` family (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being NULL,
- all families (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being not NULL.

The stats option "auc" is only available for:

- the `binomial()` family in case of the traditional projection,
- the `binomial()` family (on the original response scale) in case of the latent projection with `resp_oscale = TRUE` in combination with `<refmodel>$family$cats` being `NULL`.

Value

An object of class `vselsummary`.

See Also

`print.vselsummary()`

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Run varsel() (here without cross-validation and with small values for
  # `nterms_max`, `nclusters`, and `nclusters_pred`, but only for the sake of
  # speed in this example; this is not recommended in general):
  vs <- varsel(fit, nterms_max = 3, nclusters = 5, nclusters_pred = 10,
               seed = 5555)
  print(summary(vs), digits = 1)
}
```

varsel

Run search and performance evaluation without cross-validation

Description

Run the *search* part and the *evaluation* part for a projection predictive variable selection. The search part determines the solution path, i.e., the best submodel for each submodel size (number of predictor terms). The evaluation part determines the predictive performance of the submodels along the solution path.

Usage

```
varsel(object, ...)

## Default S3 method:
varsel(object, ...)

## S3 method for class 'refmodel'
varsel(
  object,
  d_test = NULL,
  method = NULL,
  ndraws = NULL,
  nclusters = 20,
  ndraws_pred = 400,
  nclusters_pred = NULL,
  refit_prj = !inherits(object, "datafit"),
  nterms_max = NULL,
  verbose = TRUE,
  lambda_min_ratio = 1e-05,
  nlambdas = 150,
  thresh = 1e-06,
  regul = 1e-04,
  penalty = NULL,
  search_terms = NULL,
  seed = NA,
  ...
)
```

Arguments

object	An object of class <code>refmodel</code> (returned by <code>get_refmodel()</code> or <code>init_refmodel()</code>) or an object that can be passed to argument <code>object</code> of <code>get_refmodel()</code> .
...	Arguments passed to <code>get_refmodel()</code> as well as to the divergence minimizer (during a forward search and also during the evaluation part, but the latter only if <code>refit_prj</code> is <code>TRUE</code>).
d_test	A list of the structure outlined in section "Argument d_test" below, providing test data for evaluating the predictive performance of the submodels as well as of the reference model. If <code>NULL</code> , the training data is used.
method	The method for the search part. Possible options are "L1" for L1 search and "forward" for forward search. If <code>NULL</code> , then internally, "L1" is used, except if (i) the reference model has multilevel or additive terms, (ii) if <code>!is.null(search_terms)</code> , or (iii) if the augmented-data projection is used. See also section "Details" below.
ndraws	Number of posterior draws used in the search part. Ignored if <code>nclusters</code> is not <code>NULL</code> or in case of L1 search (because L1 search always uses a single cluster). If both (<code>nclusters</code> and <code>ndraws</code>) are <code>NULL</code> , the number of posterior draws from the reference model is used for <code>ndraws</code> . See also section "Details" below.

nclusters	Number of clusters of posterior draws used in the search part. Ignored in case of L1 search (because L1 search always uses a single cluster). For the meaning of NULL, see argument ndraws. See also section "Details" below.
ndraws_pred	Only relevant if refit_prj is TRUE. Number of posterior draws used in the evaluation part. Ignored if nclusters_pred is not NULL. If both (nclusters_pred and ndraws_pred) are NULL, the number of posterior draws from the reference model is used for ndraws_pred. See also section "Details" below.
nclusters_pred	Only relevant if refit_prj is TRUE. Number of clusters of posterior draws used in the evaluation part. For the meaning of NULL, see argument ndraws_pred. See also section "Details" below.
refit_prj	A single logical value indicating whether to fit the submodels along the solution path again (TRUE) or to retrieve their fits from the search part (FALSE) before using those (re-)fits in the evaluation part.
nterms_max	Maximum submodel size (number of predictor terms) up to which the search is continued. If NULL, then $\min(19, D)$ is used where D is the number of terms in the reference model (or in search_terms, if supplied). Note that nterms_max does not count the intercept, so use <code>nterms_max = 0</code> for the intercept-only model. (Correspondingly, D above does not count the intercept.)
verbose	A single logical value indicating whether to print out additional information during the computations.
lambda_min_ratio	Only relevant for L1 search. Ratio between the smallest and largest lambda in the L1-penalized search. This parameter essentially determines how long the search is carried out, i.e., how large submodels are explored. No need to change this unless the program gives a warning about this.
nlambda	Only relevant for L1 search. Number of values in the lambda grid for L1-penalized search. No need to change this unless the program gives a warning about this.
thresh	Only relevant for L1 search. Convergence threshold when computing the L1 path. Usually, there is no need to change this.
regul	A number giving the amount of ridge regularization when projecting onto (i.e., fitting) submodels which are GLMs. Usually there is no need for regularization, but sometimes we need to add some regularization to avoid numerical problems.
penalty	Only relevant for L1 search. A numeric vector determining the relative penalties or costs for the predictors. A value of 0 means that those predictors have no cost and will therefore be selected first, whereas Inf means those predictors will never be selected. If NULL, then 1 is used for each predictor.
search_terms	Only relevant for forward search. A custom character vector of predictor term blocks to consider for the search. Section "Details" below describes more precisely what "predictor term block" means. The intercept ("1") is always included internally via <code>union()</code> , so there's no difference between including it explicitly or omitting it. The default search_terms considers all the terms in the reference model's formula.
seed	Pseudorandom number generation (PRNG) seed by which the same results can be obtained again if needed. Passed to argument seed of <code>set.seed()</code> , but can

also be NA to not call `set.seed()` at all. If not NA, then the PRNG state is reset (to the state before calling `varsel()`) upon exiting `varsel()`. Here, seed is used for clustering the reference model's posterior draws (if `!is.null(nclusters)` or `!is.null(nclusters_pred)`) and for drawing new group-level effects when predicting from a multilevel submodel (however, not yet in case of a GAMM).

Details

Arguments `ndraws`, `nclusters`, `nclusters_pred`, and `ndraws_pred` are automatically truncated at the number of posterior draws in the reference model (which is 1 for `datafits`). Using less draws or clusters in `ndraws`, `nclusters`, `nclusters_pred`, or `ndraws_pred` than posterior draws in the reference model may result in slightly inaccurate projection performance. Increasing these arguments affects the computation time linearly.

For argument `method`, there are some restrictions: For a reference model with multilevel or additive formula terms or a reference model set up for the augmented-data projection, only the forward search is available. Furthermore, argument `search_terms` requires a forward search to take effect.

L1 search is faster than forward search, but forward search may be more accurate. Furthermore, forward search may find a sparser model with comparable performance to that found by L1 search, but it may also start overfitting when more predictors are added.

An L1 search may select interaction terms before the corresponding main terms are selected. If this is undesired, choose the forward search instead.

The elements of the `search_terms` character vector don't need to be individual predictor terms. Instead, they can be building blocks consisting of several predictor terms connected by the `+` symbol. To understand how these building blocks work, it is important to know how **projpred**'s forward search works: It starts with an empty vector chosen which will later contain already selected predictor terms. Then, the search iterates over model sizes $j \in \{1, \dots, J\}$. The candidate models at model size j are constructed from those elements from `search_terms` which yield model size j when combined with the chosen predictor terms. Note that sometimes, there may be no candidate models for model size j . Also note that internally, `search_terms` is expanded to include the intercept (`"1"`), so the first step of the search (model size 1) always consists of the intercept-only model as the only candidate.

As a `search_terms` example, consider a reference model with formula $y \sim x1 + x2 + x3$. Then, to ensure that `x1` is always included in the candidate models, specify `search_terms = c("x1", "x1 + x2", "x1 + x3", "x1 + x2 + x3")`. This search would start with $y \sim 1$ as the only candidate at model size 1. At model size 2, $y \sim x1$ would be the only candidate. At model size 3, $y \sim x1 + x2$ and $y \sim x1 + x3$ would be the two candidates. At the last model size of 4, $y \sim x1 + x2 + x3$ would be the only candidate. As another example, to exclude `x1` from the search, specify `search_terms = c("x2", "x3", "x2 + x3")`.

Value

An object of class `vsel`. The elements of this object are not meant to be accessed directly but instead via helper functions (see the main vignette and [projpred-package](#)).

Argument `d_test`

If not `NULL`, then `d_test` needs to be a list with the following elements:

- `data`: a `data.frame` containing the predictor variables for the test set.
- `offset`: a numeric vector containing the offset values for the test set (if there is no offset, use a vector of zeros).
- `weights`: a numeric vector containing the observation weights for the test set (if there are no observation weights, use a vector of ones).
- `y`: a vector or a factor containing the response values for the test set. In case of the latent projection, this has to be a vector containing the *latent* response values, but it can also be a vector full of NAs if latent-scale post-processing is not needed.
- `y_yscale`: Only needs to be provided in case of the latent projection where this needs to be a vector or a factor containing the *original* (i.e., non-latent) response values for the test set.

See Also

`cv_varsel()`

Examples

```
if (requireNamespace("rstanarm", quietly = TRUE)) {
  # Data:
  dat_gauss <- data.frame(y = df_gaussian$y, df_gaussian$x)

  # The "stanreg" fit which will be used as the reference model (with small
  # values for `chains` and `iter`, but only for technical reasons in this
  # example; this is not recommended in general):
  fit <- rstanarm::stan_glm(
    y ~ X1 + X2 + X3 + X4 + X5, family = gaussian(), data = dat_gauss,
    QR = TRUE, chains = 2, iter = 500, refresh = 0, seed = 9876
  )

  # Run varsel() (here without cross-validation and with small values for
  # `nterms_max`, `nclusters`, and `nclusters_pred`, but only for the sake of
  # speed in this example; this is not recommended in general):
  vs <- varsel(fit, nterms_max = 3, nclusters = 5, nclusters_pred = 10,
    seed = 5555)

  # Now see, for example, `?print.vsel`, `?plot.vsel`, `?suggest_size.vsel`,
  # and `?ranking` for possible post-processing functions.
}
```

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