Package ‘shapr’
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Title Prediction Explanation with Dependence-Aware Shapley Values
Description Complex machine learning models are often hard to interpret. However, in many situations it is crucial to understand and explain why a model made a specific prediction. Shapley values is the only method for such prediction explanation framework with a solid theoretical foundation. Previously known methods for estimating the Shapley values do, however, assume feature independence. This package implements the method described in Aas, Jullum and Løland (2019) <arXiv:1903.10464>, which accounts for any feature dependence, and thereby produces more accurate estimates of the true Shapley values.


BugReports https://github.com/NorskRegnesentral/shapr/issues
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Author Nikolai Sellereite [aut] (<https://orcid.org/0000-0002-4671-0337>), Martin Jullum [cre, aut] (<https://orcid.org/0000-0003-3908-5155>), Annabelle Redelmeier [aut], Anders Løland [ctb]
**Explanation**

Explain the output of machine learning models with more accurately estimated Shapley values

**Usage**

```r
explain(x, explainer, approach, prediction_zero, ...)
```

**Description**

Explain the output of machine learning models with more accurately estimated Shapley values

**S3 method for class 'empirical'**

```r
explain(
  x,
  explainer,
  approach,
  prediction_zero,
  type = "fixed_sigma",
  fixed_sigma_vec = 0.1,
  n_samples_aicc = 1000,
  eval_max_aicc = 20,
  start_aicc = 0.1,
  w_threshold = 0.95,
  ...
)
```

**S3 method for class 'gaussian'**

```r
explain(
```
explain

x,
explainer,
approach,
prediction_zero,
mu = NULL,
cov_mat = NULL,
...
)

## S3 method for class 'copula'
explain(x, explainer, approach, prediction_zero, ...)

## S3 method for class 'ctree'
explain(
  x,
explainer,
approach,
prediction_zero,
mincriterion = 0.95,
minsplit = 20,
minbucket = 7,
sample = TRUE,
...
)

## S3 method for class 'combined'
explain(
  x,
explainer,
approach,
prediction_zero,
mu = NULL,
cov_mat = NULL,
...
)

## S3 method for class 'ctree_comb_mincrit'
explain(x, explainer, approach, prediction_zero, mincriterion, ...)

Arguments

x  A matrix or data.frame. Contains the the features, whose predictions ought to be explained (test data).
explainer  An explainer object to use for explaining the observations. See shapr.
approach  Character vector of length 1 or n_features. n_features equals the total number of features in the model. All elements should either be "gaussian", "copula", "empirical", or "ctree". See details for more information.
prediction_zero  
Numeric. The prediction value for unseen data, typically equal to the mean of  
the response.

...  
Additional arguments passed to prepare_data

type  
Character. Should be equal to either "independence", "fixed_sigma", "AICc_each_k"  
or "AICc_full".

fixed_sigma_vec  
Numeric. Represents the kernel bandwidth. Note that this argument is only  
applicable when approach = "empirical", and type = "fixed_sigma"

n_samples_aicc  
Positive integer. Number of samples to consider in AICc optimization. Note  
that this argument is only applicable when approach = "empirical", and type  
is equal to "AICc_each_k" or "AICc_full"

eval_max_aicc  
Positive integer. Maximum number of iterations when optimizing the AICc.  
Note that this argument is only applicable when approach = "empirical", and  
type is either equal to "AICc_each_k" or "AICc_full"

start_aicc  
Numeric. Start value of sigma when optimizing the AICc. Note that this  
argument is only applicable when approach = "empirical", and type is either  
equal to "AICc_each_k" or "AICc_full"

w_threshold  
Positive integer between 0 and 1.

mu  
Numeric vector. (Optional) Containing the mean of the data generating  
distribution. If NULL the expected values are estimated from the data. Note that  
this is only used when approach = "gaussian".

cov_mat  
Numeric matrix. (Optional) Containing the covariance matrix of the data  
generating distribution. NULL means it is estimated from the data if needed (in  
the Gaussian approach).

mincriterion  
Numeric value or vector where length of vector is the number of features in  
model. Value is equal to 1 - alpha where alpha is the nominal level of the  
conditional independence tests. If it is a vector, this indicates which mincriterion to  
use when conditioning on various numbers of features.

minsplits  
Numeric value. Equal to the value that the sum of the left and right daughter  
nodes need to exceed.

minbucket  
Numeric value. Equal to the minimum sum of weights in a terminal node.

sample  
Boolean. If TRUE, then the method always samples n_samples from the leaf  
(with replacement). If FALSE and the number of obs in the leaf is less than  
n_samples, the method will take all observations in the leaf. If FALSE and  
the number of obs in the leaf is more than n_samples, the method will sample  
n_samples (with replacement). This means that there will always be sampling  
in the leaf unless sample = FALSE AND the number of obs in the node is less  
than n_samples.

Details  
The most important thing to notice is that shapr has implemented four different approaches for  
estimating the conditional distributions of the data, namely "empirical", "gaussian", "copula"  
and "ctree".
In addition, the user also has the option of combining the four approaches. E.g. if you're in a situation where you have trained a model the consists of 10 features, and you'd like to use the "gaussian" approach when you condition on a single feature, the "empirical" approach if you condition on 2-5 features, and "copula" version if you condition on more than 5 features this can be done by simply passing `approach = c("gaussian",rep("empirical",4),rep("copula",5))`. If "approach[i]" = "gaussian" it means that you'd like to use the "gaussian" approach when conditioning on i features.

**Value**

Object of class c("shapr","list"). Contains the following items:

- `dt` data.table
- `model` Model object
- `p` Numeric vector
- `x_test` data.table

Note that the returned items `model`, `p` and `x_test` are mostly added due to the implementation of `plot.shapr`. If you only want to look at the numerical results it is sufficient to focus on `dt`. `dt` is a data.table where the number of rows equals the number of observations you'd like to explain, and the number of columns equals `m + 1`, where `m` equals the total number of features in your model.

If `dt[i,j + 1] > 0` it indicates that the j-th feature increased the prediction for the i-th observation. Likewise, if `dt[i,j + 1] < 0` it indicates that the j-th feature decreased the prediction for the i-th observation. The magnitude of the value is also important to notice. E.g. if `dt[i,k + 1]` and `dt[i,j + 1]` are greater than 0, where `j != k`, and `dt[i,k + 1] > dt[i,j + 1]` this indicates that feature `j` and `k` both increased the value of the prediction, but that the effect of the `k`-th feature was larger than the `j`-th feature.

The first column in `dt`, called 'none', is the prediction value not assigned to any of the features ($\phi_0$). It's equal for all observations and set by the user through the argument `prediction_zero`. In theory this value should be the expected prediction without conditioning on any features. Typically we set this value equal to the mean of the response variable in our training data, but other choices such as the mean of the predictions in the training data are also reasonable.

**Author(s)**

Camilla Lingjaerde, Nikolai Sellereite, Martin Jullum, Annabelle Redelmeier

**Examples**

```
if (requireNamespace("MASS", quietly = TRUE)) {
  # Load example data
  data("Boston", package = "MASS")

  # Split data into test- and training data
  x_train <- head(Boston, -3)
  x_test <- tail(Boston, 3)

  # Fit a linear model
  model <- lm(medv ~ lstat + rm + dis + indus, data = x_train)
```
feature_combinations

Define feature combinations, and fetch additional information about each unique combination
Description

Define feature combinations, and fetch additional information about each unique combination

Usage

feature_combinations(
  m,
  exact = TRUE,
  n_combinations = 200,
  weight_zero_m = 10^6
)

Arguments

- **m**: Positive integer. Total number of features.
- **exact**: Logical. If TRUE all \(2^m\) combinations are generated, otherwise a subsample of the combinations is used.
- **n_combinations**: Positive integer. Note that if exact = TRUE, n_combinations is ignored. However, if \(m > 12\) you’ll need to add a positive integer value for n_combinations.
- **weight_zero_m**: Numeric. The value to use as a replacement for infinite combination weights when doing numerical operations.

Value

A data.table that contains the following columns:

- **id_combination**: Positive integer. Represents a unique key for each combination. Note that the table is sorted by id_combination, so that is always equal to x[["id_combination"]]= 1:nrow(x).
- **features**: List. Each item of the list is an integer vector where features[[i]] represents the indices of the features included in combination i. Note that all the items are sorted such that features[[i]] == sort(features[[i]]) is always true.
- **n_features**: Vector of positive integers. n_features[i] equals the number of features in combination i, i.e. n_features[i] = length(features[[i]])..
- **N**: Positive integer. The number of unique ways to sample n_features[i] features from m different features, without replacement.

Author(s)

Nikolai Sellereite, Martin Jullum

Examples

# All combinations
x <- feature_combinations(m = 3)
nrow(x) # Equals 2^3 = 8

# Subsample of combinations
x <- feature_combinations(exact = FALSE, m = 10, n_combinations = 1e2)
**Description**

Initiate the making of dummy variables

**Usage**

```r
make_dummies(traindata, testdata)
```

**Arguments**

- `traindata`: data.table or data.frame.
- `testdata`: data.table or data.frame. New data that has the same feature names, types, and levels as `traindata`.

**Value**

A list that contains the following entries:

- `feature_list`: List. Output from `check_features`
- `train_dummies`: A data.frame containing all of the factors in `traindata` as one-hot encoded variables.
- `test_dummies`: A data.frame containing all of the factors in `testdata` as one-hot encoded variables.
- `traindata_new`: Original `traindata` with correct column ordering and factor levels. To be passed to `shapr`.
- `testdata_new`: Original `testdata` with correct column ordering and factor levels. To be passed to `explain`.

**Author(s)**

Annabelle Redelmeier, Martin Jullum

**Examples**

```r
if (requireNamespace("MASS", quietly = TRUE)) {
  data("Boston", package = "MASS")
  x_var <- c("lstat", "rm", "dis", "indus")
  y_var <- "medv"
  x_train <- as.data.frame(Boston[401:411, x_var])
  y_train <- Boston[401:408, y_var]
  x_test <- as.data.frame(Boston[1:4, x_var])

  # convert to factors for illustrational purpose
  x_train$rm <- factor(round(x_train$rm))
  x_test$rm <- factor(round(x_test$rm), levels = levels(x_train$rm))

  # initiate making of dummy variables
  dummy_list <- make_dummies(x_train, x_test)
}
```
```r
dummylist <- make_dummies(traindata = x_train, testdata = x_test)
}
```

---

**plot.shapr**  
*Plot of the Shapley value explanations*

**Description**

Plots the individual prediction explanations.

**Usage**

```r
## S3 method for class 'shapr'
plot(
  x,
  digits = 3,
  plot_phi0 = TRUE,
  index_x_test = NULL,
  top_k_features = NULL,
  ...
)
```

**Arguments**

- `x`: An `shapr` object. See `explain`.
- `digits`: Integer. Number of significant digits to use in the feature description.
- `plot_phi0`: Logical. Whether to include \( \phi_0 \) in the plot.
- `index_x_test`: Integer vector. Which of the test observations to plot. E.g. if you have explained 10 observations using `explain`, you can generate a plot for the first 5 observations by setting `index_x_test = 1:5`.
- `top_k_features`: Integer. How many features to include in the plot. E.g. if you have 15 features in your model you can plot the 5 most important features, for each explanation, by setting `top_k_features = 1:5`.
- `...`: Currently not used.

**Details**

See vignette("understanding_shapr",package = "shapr") for an example of how you should use the function.

**Value**

A `ggplot` object with plots of the Shapley value explanations.
Author(s)

Martin Jullum

Examples

```r
if (requireNamespace("MASS", quietly = TRUE)) {
  # Load example data
  data("Boston", package = "MASS")

  # Split data into test- and training data
  x_train <- head(Boston, -3)
  x_test <- tail(Boston, 3)

  # Fit a linear model
  model <- lm(medv ~ lstat + rm + dis + indus, data = x_train)

  # Create an explainer object
  explainer <- shapr(x_train, model)

  # Explain predictions
  p <- mean(x_train$medv)

  # Empirical approach
  explanation <- explain(x_test, explainer, approach = "empirical",
                         prediction_zero = p, n_samples = 1e2)

  if (requireNamespace("ggplot2", quietly = TRUE)) {
    # Plot the explanation (this function)
    plot(explanation)
  }
}
```

---

**shapr**

Create an explainer object with Shapley weights for test data.

Description

Create an explainer object with Shapley weights for test data.

Usage

```r
shapr(x, model, n_combinations = NULL)
```
Arguments

- **x**: Numeric matrix or data.frame/data.table. Contains the data used to estimate the (conditional) distributions for the features needed to properly estimate the conditional expectations in the Shapley formula.

- **model**: The model whose predictions we want to explain. Run `shapr:::get_supported_models()` for a table of which models `shapr` supports natively.

- **n_combinations**: Integer. The number of feature combinations to sample. If `NULL`, the exact method is used and all combinations are considered. The maximum number of combinations equals $2^{\text{ncol}(x)}$.

Value

Named list that contains the following items:

- **exact**: Boolean. Equals `TRUE` if `n_combinations = NULL` or `n_combinations < 2^{\text{ncol}(x)}`, otherwise `FALSE`.

- **n_features**: Positive integer. The number of columns in `x`

- **S**: Binary matrix. The number of rows equals the number of unique combinations, and the number of columns equals the total number of features. I.e. let's say we have a case with three features. In that case we have $2^3 = 8$ unique combinations. If the j-th observation for the i-th row equals 1 it indicates that the j-th feature is present in the i-th combination. Otherwise it equals 0.

- **W**: Second item

- **X**: data.table. Returned object from `feature_combinations`

- **x_train**: data.table. Transformed `x` into a data.table.

- **feature_list**: List. The `updated_feature_list` output from `preprocess_data`

In addition to the items above, `model` and `n_combinations` are also present in the returned object.

Author(s)

Nikolai Sellereite

Examples

```r
if (requireNamespace("MASS", quietly = TRUE)) {
  # Load example data
data("Boston", package = "MASS")
df <- Boston

  # Example using the exact method
x_var <- c("lstat", "rm", "dis", "indus")
y_var <- "medv"
dfl <- df[, x_var]
model <- lm(medv ~ lstat + rm + dis + indus, data = dfl)
explainer <- shapr(dfl, model)
print(nrow(explainer$X))
```
# 16 (which equals 2^4)

# Example using approximation
y_var <- "medv"
x_var <- setdiff(colnames(df), y_var)
model <- lm(medv ~ ., data = df)
df2 <- df[, x_var]
explainer <- shapr(df2, model, n_combinations = 1e3)
print(nrow(explainer$X))

# Example using approximation where n_combinations > 2^m
x_var <- c("lstat", "rm", "dis", "indus")
y_var <- "medv"
df3 <- df[, x_var]
model <- lm(medv ~ lstat + rm + dis + indus, data = df)
explainer <- shapr(df3, model, n_combinations = 1e3)
print(nrow(explainer$X))
# 16 (which equals 2^4)
Index

explain, 2, 8, 9

feature_combinations, 6, 11

make_dummies, 8

plot.shapr, 9
prepare_data, 4
preprocess_data, 11

shapr, 3, 8, 10
shapr:::get_supported_models(), 11