Package ‘pcFactorStan’

October 14, 2022

Title Stan Models for the Paired Comparison Factor Model
Version 1.5.3
Description Provides convenience functions and pre-programmed
Stan models related to the paired comparison factor model. Its purpose
is to make fitting paired comparison data using Stan easy. This
License GPL (>= 3)
URL https://github.com/jpritikin/pcFactorStan
BugReports https://github.com/jpritikin/pcFactorStan/issues
Depends R (>= 3.4), methods, Rcpp (>= 0.12.0)
Imports rstan (>= 2.18), rstantools (>= 2.1.1), reshape2, mvtnorm,
igraph, loo, lifecycle
Suggests knitr, rmarkdown, testthat, shiny, ggplot2, covr, qgraph,
Matrix
LinkingTo Rcpp (>= 0.12.0), RcppEigen (>= 0.3.3.3.0), RcppParallel (>=
5.0.2), StanHeaders (>= 2.18.0), BH (>= 1.66.0), rstan (>=
2.18.1)
VignetteBuilder knitr
RdMacros lifecycle
Encoding UTF-8
LazyData true
NeedsCompilation yes
RoxygenNote 7.1.2
SystemRequirements GNU make
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Repository CRAN
Date/Publication 2021-09-25 15:50:02 UTC
R topics documented:

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**pcFactorStan-package**  
*Stan Models for the Pairwise Comparison Factor Model*

**Description**

**pcFactorStan** makes it easy to fit the paired comparison factor model using **rstan**.

A user will generally want to use **prepData** and **pcStan** to fit a model.

The package includes a number of Stan models (see **findModel** for a list) and an example dataset **phyActFlowPropensity**.

After gaining some experience with the pre-defined models, we anticipate that users may write their own Stan models and fit them with **stan**, for which **pcStan** is a wrapper.
**calibrateItems**  
*Determine the optimal scale constant for a set of items*

**Description**

Data are passed through `filterGraph` and `normalizeData`. Then the ‘unidim.adapt’ model is fit to each item individually. A larger `varCorrection` will obtain a more accurate scale, but is also more likely to produce an intractable model. A good compromise is between 5.0 and 9.0.

**Usage**

```r
calibrateItems(
  df,
  iter = 2000L,
  chains = 4L,
  varCorrection = 5,
  maxAttempts = 5L,
  ...
)
```

**Arguments**

- `df`  
a data frame with pairs of vertices given in columns `pa1` and `pa2`, and item response data in other columns
- `iter`  
A positive integer specifying the number of iterations for each chain (including warmup).
- `chains`  
A positive integer specifying the number of Markov chains.
- `varCorrection`  
A correction factor greater than or equal to 1.0
- `maxAttempts`  
How many times to try re-running a model with more iterations.
- `...`  
Additional options passed to `stan`.

**Value**

A data.frame (one row per item) with the following columns:

- `item`  
Name of the item
- `iter`  
Number of iterations per chain
- `divergent`  
Number of divergent transitions observed after warmup
- `treedepth`  
Number of times the treedepth was exceeded
- `low_bfmi`  
Number of chains with low E-BFMI
- `n_eff`  
Minimum effective number of samples across all parameters
- `Rhat`  
Maximum Rhat across all parameters
- `scale`  
Median marginal posterior of scale
- `thetaVar`  
Median variance of theta (latent scores)
References

See Also
check_hmc_diagnostics

Examples

```r
result <- calibrateItems(phyActFlowPropensity) # takes more than 5 seconds
print(result)
```

## cmp_probs

**Item response function for pairwise comparisons**

### Description
Use `itemModelExplorer` to explore the item model. In this shiny app, the discrimination parameter does what is customary in item response models. However, it is not difficult to show that discrimination is a function of thresholds and scale. That is, discrimination is not an independent parameter. In paired comparison models, discrimination and measurement error are confounded.

### Usage

```r
cmp_probs(alpha, scale, pa1, pa2, thRaw)
```

### Arguments

- **alpha**: discrimination parameter
- **scale**: scale correction factor
- **pa1**: first latent worth
- **pa2**: second latent worth
- **thRaw**: vector of positive thresholds

### Details
The thresholds are parameterized as the difference from the previous threshold. For example, thresholds c(0.5, 0.6) are not at the same location but are at locations c(0.5, 1.1). Thresholds are symmetric. If there is one threshold then the model admits three possible response outcomes (e.g. win, tie, and lose). Responses are always stored centered with zero representing a tie. Therefore, it is necessary to add one plus the number of thresholds to response data to index into the vector returned by `cmp_probs`. For example, if our response data is (-1, 0, 1) and has one threshold then we would add 2 (1 + 1 threshold) to obtain the indices (1, 2, 3).
**Value**

A vector of probabilities of observing each outcome

**Math**

Up until version 1.4, the item response model was based on the partial credit model (Masters, 1982). In version 1.5, the graded response model is used instead (Samejima, 1969). The advantage of the graded response model is greater independence among threshold parameters and the ability to compute only the parts of the model that are actually needed given particular observations. The curves predicted by both models are similar and should obtain similar results in data analyses.

**References**


**Examples**

```r
# Returns probabilities of
cmp_probs(1,1,0,1,.8)

# Add another threshold for a symmetric 3 point Likert scale
cmp_probs(1,1,0,.5,c(.8, 1.6))
```

---

### filterGraph

*Filter graph to remove vertices that are not well connected*

**Description**

Vertices not part of the largest connected component are excluded (Hopcroft & Tarjan, 1973). Vertices that have fewer than $\text{minAny}$ edges and are not connected to $\text{minDifferent}$ or more different vertices are excluded. For example, vertex ‘a’ connected to vertices ‘b’ and ‘c’ will be included so long as these vertices are part of the largest connected component.

**Usage**

```r
filterGraph(df, minAny = 11L, minDifferent = 2L)
```

**Arguments**

- **df**
  - a data frame with pairs of vertices given in columns `pa1` and `pa2`, and item response data in other columns
- **minAny**
  - the minimum number of edges
- **minDifferent**
  - the minimum number of vertices
Details

Given that \( \text{minDifferent} \) defaults to 2, if activity \( A \) was compared to at least two other activities, \( B \) and \( C \), then \( A \) is retained. The rationale is that, although little may be learned about \( A \), there may be a transitive relationship, such as \( B < A < C \), by which the model can infer that \( B < C \). Therefore, per-activity sample size is less of a concern when the graph is densely connected.

A young novice asked the wise master, "Why is 11 the default \( \text{minAny} \) instead of 10?" The master answered, "Because 11 is a prime number."

Value

The same graph excluding some vertices.

References


Examples

```r
df <- filterGraph(phyActFlowPropensity[,c(paste0('pa',1:2), 'predict'))]
head(df)
```

---

**findModel**

*Given a model name, return stanmodel object*

Description

This is a convenience function to help you look up the path to an appropriate model for your data.

Usage

```r
findModel(model = NULL)
```

Arguments

- `model` the name of a model

Details

There are essentially three models: `unidim`, `covariance`, and `factor`. `unidim` analyzes a single item. `covariance` is suitable for two or more items. Once you have vetted your items with the `unidim` and `covariance` models, then you can try the `factor` model. For each model, there is a `_ll` variation. This model includes row-wise log likelihoods suitable for feeding to `loo` for efficient approximate leave-one-out cross-validation (Vehtari, Gelman, & Gabry, 2017).

There is also a special model `unidim_adapt`. Except for this model, the other models require a scaling constant. To find an appropriate scaling constant, we recommend fitting `unidim_adapt` to each
item separately and then take the median of median point estimates to set the scale. ‘unidim_adapt’ requires a varCorrection constant. In general, a varCorrection of 2.0 or 3.0 should provide optimal results.

Since version 1.1.0, the factor model permits an arbitrary number of factors and arbitrary factor-to-item paths. If you were using the old factor model, you’ll need to update your code to call prepSingleFactorModel. Arbitrary factor model structure should be specified using prepFactorModel. The single factor model is called ‘factor1’ and the general factor model is called ‘factor’.

Value

An instance of S4 class stanmodel that can be passed to pcStan.

References


See Also

toLoo

Examples

findModel() # shows available models
findModel('unidim')

---

**generateCovItems**

Generate paired comparison data with random correlations between items

Description

If you need access to the correlation matrix used to generate the absolute latent scores then you will need to generate them yourself. This is not difficult. See how in the example.

Usage

generateCovItems(df, numItems, th = 0.5, name, ..., scale = 1, alpha = 1)

Arguments

df               a data frame with pairs of vertices given in columns pa1 and pa2, and item response data in other columns
numItems         how many items to create
th               a vector of thresholds
name             a vector of item names
generateFactorItems

Generate paired comparison data for a factor model

Description

Generate paired comparison data given a mapping from factors to items.

Usage

generateFactorItems(
  df,
  path,
  factorScalePrior = deprecated(),
  th = 0.5,
)
Arguments

- **df**: A data frame with pairs of vertices given in columns `pa1` and `pa2`, and item response data in other columns.
- **path**: A named list of item names.
- **factorScalePrior**: A named numeric vector (deprecated).
- **th**: A vector of thresholds.
- **name**: A vector of item names.
- **...**: Not used. Forces remaining arguments to be specified by name.
- **scale**: A vector of scaling constants.
- **alpha**: A vector of item discriminations.

Details

For each factor, you need to specify its name and which items it predicts. The connections from factors to items is specified by the `path` argument. Both factors and items are specified by name (not index).

Path proportions (factor-to-item loadings) are sampled from a logistic transformed normal distribution with scale 0.6. A few attempts are made to resample path proportions if any of the item proportions sum to more than 1.0. An exception will be raised if repeated attempts fail to produce viable proportion assignments.

Value

The given data frame `df` with additional columns for each item. In addition, you can obtain path proportions (factor-to-item loadings) from `attr(df, "pathProp")`, the factor scores from `attr(df, "score")`, and latent worths from `attr(df, "worth")`.

Response model

See `cmp_probs` for details.

Backward incompatibility

The function `generateFactorItems` was renamed to `generateSingleFactorItems` (version 1.1.0) to make space for a more flexible factor model with an arbitrary number of factors and arbitrary factor-to-item loading pattern. If you don’t need this flexibility, you can call the old function `generateSingleFactorItems`. 
References


See Also

To fit a factor model: prepFactorModel

Other item generators: generateCovItems(), generateItem(), generateSingleFactorItems()

Examples

```r
df <- twoLevelGraph(letters[1:10], 100)
df <- generateFactorItems(df, list(f1=paste0('i',1:4),
                                 f2=paste0('i',2:4)),
                          c(f1=0.9, f2=0.5))
head(df)
attr(df, "pathProp")
attr(df, "score")
attr(df, "worth")
```

---

**generateItem**

Generate paired comparison data for one or more items given absolute latent scores

**Description**

To add a single item, theta should be a vector of latent scores. To add multiple items at a time, theta should be a matrix with one item in each column. Item names can be given as the colnames of theta.

The interpretation of theta depends on the context where the data were generated. For example, in chess, theta represents unobserved chess skill that is partially revealed by match outcomes.

The graph can be regarded as undirected, but data are generated relative to the order of vertices within each row. Vertices do not commute. For example, a -1 for vertices ‘a’ and ‘b’ is the same as 1 for vertices ‘b’ and ‘a’.

**Usage**

```r
generateItem(df, theta, th = 0.5, name, ..., scale = 1, alpha = 1)
```

**Arguments**

- `df` a data frame with pairs of vertices given in columns pa1 and pa2, and item response data in other columns
- `theta` a vector or matrix of absolute latent scores. See details below.
- `th` a vector of thresholds
generateSingleFactorItems

name  a vector of item names
...
Not used. Forces remaining arguments to be specified by name.
scale  a vector of scaling constants
alpha  a vector of item discriminations

Value

The given data.frame df with additional columns for each item.

Response model

See cmp_probs for details.

See Also

Other item generators: generateCovItems(), generateFactorItems(), generateSingleFactorItems()

Examples

def <- roundRobinGraph(letters[1:5], 40)
def <- generateItem(df)

df <- generateSingleFactorItems(df, prop = 0.5, name, ..., scale = 1, alpha = 1)

Description

Imagine that there are people that play in tournaments of more than one board game. For example, the computer player AlphaZero (Silver et al. 2018) has trained to play chess, shogi, and Go. We can take the tournament match outcome data and find rankings among the players for each of these games. We may also suspect that there is a latent board game skill that accounts for some proportion of the variance in the per-board game rankings.

Usage

generateSingleFactorItems(df, prop = 0.5, name, ..., scale = 1, alpha = 1)

Arguments

df  a data frame with pairs of vertices given in columns pa1 and pa2, and item response data in other columns
prop the number of items or a vector of signed proportions of variance
th  a vector of thresholds
name  a vector of item names
Not used. Forces remaining arguments to be specified by name.

scale
da vector of scaling constants

alpha
da vector of item discriminations

**Value**

The given data.frame `df` with additional columns for each item.

**Response model**

See `cmp.probs` for details.

**Backward incompatibility**

The function `generateFactorItems` was renamed to `generateSingleFactorItems` (version 1.1.0) to make space for a more flexible factor model with an arbitrary number of factors and arbitrary factor-to-item loading pattern. If you don’t need this flexibility, you can call the old function `generateSingleFactorItems`.

**References**


**See Also**

Other item generators: `generateCovItems()`, `generateFactorItems()`, `generateItem()`

**Examples**

```r
df <- twoLevelGraph(letters[1:10], 100)
df <- generateSingleFactorItems(df, 3)
```

**Description**

When data `dl` and fitted model `fit` are provided, the item parameters associated with `item` are loaded for inspection.

**Usage**

`itemModelExplorer(dl = NULL, fit = NULL, item = NULL)`
normalizeData

Arguments

dl a data list prepared by prepData
fit a stanfit object
item name of the item to visualize

Response model

See cmp_probs for details.

Examples

itemModelExplorer()  # will launch a browser in RStudio

df <- data.frame(pa1=NA, pa2=NA, i1=c(1, -1))
df[1,paste0('pa',1:2)] <- c('a','b')
df[2,paste0('pa',1:2)] <- c('b','a')
normalizeData(df)
outlierTable

List observations with Pareto values larger than a given threshold

Description

The function `prepCleanData` compresses observations into the most efficient format for evaluation by Stan. This function maps indices of observations back to the actual observations, filtering by the largest Pareto k values. It is assumed that data was processed by `normalizeData` or is in the same order as seen by `prepCleanData`.

Usage

```r
outlierTable(data, x, threshold = 0.5)
```

Arguments

- `data`: a data list prepared for processing by Stan
- `x`: An object created by `loo`
- `threshold`: threshold is the minimum k value to include

Value

A data.frame (one row per observation) with the following columns:

- **pa1**: Name of object 1
- **pa2**: Name of object 2
- **item**: Name of item
- **pick**: Observed response
- **k**: Associated Pareto k value

See Also

- `toLoo`, `pareto_k_ids`

Examples

```r
palist <- letters[1:10]
df <- twoLevelGraph(palist, 300)
theta <- rnorm(length(palist))
names(theta) <- palist
df <- generateItem(df, theta, th=rep(0.5, 4))

df <- filterGraph(df)
df <- normalizeData(df)
dl <- prepCleanData(df)
dl$scale <- 1.5
```
parDistributionCustom

Produce data suitable for plotting parameter distributions

Usage

parDistributionCustom(
  fit,                  
  pars,                 
  nameVec,              
  label = withoutIndex(pars[1]), 
  samples = 500
)

parDistributionFor(fit, pi, samples = 500)

Arguments

fit        a stanfit object
pars       a vector of parameter names
nameVec    a vector of explanatory parameters names
label      column name for nameVec
samples    number of posterior samples
pi          a data.frame returned by parInterval

Value

A data.frame with the following columns:

sample    Sample index
label     A name from nameVec
value     A single sample of the associated parameter

See Also

Other data extractor: parInterval(), responseCurve()
parInterval

Produce data suitable for plotting parameter estimates

Description

Produce data suitable for plotting parameter estimates

Usage

parInterval(fit, pars, nameVec, label = withoutIndex(pars[1]), width = 0.8)

Arguments

- fit: a **stanfit** object
- pars: a vector of parameter names
- nameVec: a vector of explanatory parameters names
- label: column name for nameVec
- width: a width in probability units for the uncertainty interval

Value

A data.frame with the following columns:

- **L**: Lower quantile
- **M**: Median
- **U**: Upper quantile
- **label**: nameVec

See Also

Other data extractor: `parDistributionCustom()`, `responseCurve()`

Examples

vignette('manual', 'pcFactorStan')
pcStan  

Fit a paired comparison Stan model

Description

Uses `findModel` to find the appropriate model and then invokes `sampling`.

Usage

pcStan(model, data, ...)

Arguments

model  
the name of a model

data  
a data list prepared for processing by Stan

...  
Additional options passed to `stan`.

Value

A `stanfit` object.

An object of S4 class `stanfit`.

See Also

See `sampling`, for which this function is a wrapper, for additional options. See `prepData` to create a suitable data list. See `print.stanfit` for ways of getting tables summarizing parameter posteriors.

`calibrateItems, outlierTable`

Examples

dl <- prepData(phyActFlowPropensity[,c(1,2,3)])
dl$varCorrection <- 5.0
pcStan('unidim_adapt', data=d1)  # takes more than 5 seconds

phyActFlowPropensity  
Physical activity flow propensity
Description

A dataset containing paired comparisons of 87 physical activities on 16 flow-related facets. Participants submitted two activities using free-form input. These activities were substitute into item templates. For example, the ‘predict’ item asked, “How predictable is the action?” with response options:

- A1 is much more predictable than A2.
- A1 is somewhat more predictable than A2.
- Both offer roughly equal predictability.
- A2 is somewhat more predictable than A1.
- A2 is much more predictable than A1.

Most items were adapted from Jackson & Eklund (2002).

Usage

phyActFlowPropensity

Format

A data.frame with one row per activity comparison and items in the columns. All item responses are between -2 and 2. Zero indicates that both activities were judged equal on the trait.

Source

A manuscript fully describing the study is in preparation. Data are made available under the Community Data License Agreement - Sharing - Version 1.0

References


prepCleanData

Transforms data into a form tailored for efficient evaluation by Stan

Description

Vertex names, if not already factors, are converted to factors. The number of thresholds per item is determined by the largest absolute response value. Missing responses are filtered out. Responses on the same pair of vertices on the same item are grouped together. Within a vertex pair and item, responses are ordered from negative to positive.

Usage

prepCleanData(df)
**Arguments**

- `df` a data frame with pairs of vertices given in columns `pa1` and `pa2`, and item response data in other columns

**Details**

Note: Reordering of responses is likely unless something like `normalizeData` has been used with `.sortRows=TRUE`.

**Value**

a data list suitable for passing as the `data` argument to `pcStan` or `stan`

**See Also**

Other data preppers: `prepData()`, `prepFactorModel()`, `prepSingleFactorModel()`

**Examples**

```r
df <- prepCleanData(phyActFlowPropensity)
str(df)
```

---

**Description**

Invokes `filterGraph` and `normalizeData`. Vertex names, if not already factors, are converted to factors. The number of thresholds per item is determined by the largest absolute response value. Missing responses are filtered out. Responses on the same pair of vertices on the same item are grouped together. Within a vertex pair and item, responses are ordered from negative to positive.

**Usage**

```r
prepData(df)
```

**Arguments**

- `df` a data frame with pairs of vertices given in columns `pa1` and `pa2`, and item response data in other columns

**Value**

a data list suitable for passing as the `data` argument to `pcStan` or `stan`

**See Also**

Other data preppers: `prepCleanData()`, `prepFactorModel()`, `prepSingleFactorModel()`
Examples

```r
df <- prepData(phyActFlowPropensity)
str(df)
```

Description

Specify a factor model with an arbitrary number of factors and arbitrary factor-to-item structure.

Usage

```r
prepFactorModel(
  data, 
  path, 
  factorScalePrior = deprecated(), 
  psiScalePrior = deprecated()
)
```

Arguments

- `data` a data list prepared for processing by Stan
- `path` a named list of item names
- `factorScalePrior` a named numeric vector (deprecated)
- `psiScalePrior` matrix of priors for factor correlations (deprecated)

Details

For each factor, you need to specify its name and which items it predicts. The connections from factors to items is specified by the `path` argument. Both factors and items are specified by name (not index).

Value

a data list suitable for passing as the data argument to `pcStan` or `stan`

See Also

To simulate data from a factor model: `generateFactorItems`
Other factor model: `prepSingleFactorModel()`
Other data preppers: `prepCleanData()`, `prepData()`, `prepSingleFactorModel()`
prepSingleFactorModel

Specify a single factor model

Description

Specify a single latent factor with a path to each item.

Usage

prepSingleFactorModel(data, factorScalePrior = deprecated())

Arguments

data a data list prepared for processing by Stan
factorScalePrior a named numeric vector (deprecated)

Value

a data list suitable for passing as the data argument to pcStan or stan

See Also

Other factor model: prepFactorModel()
Other data preppers: prepCleanData(), prepData(), prepFactorModel()

Examples

dl <- prepData(phyActFlowPropensity)
dl <- prepSingleFactorModel(dl)
str(dl)
responseCurve  

*Produce data suitable for plotting item response curves*

**Description**

Selects samples random draws from the posterior and evaluates the item response curve on the grid given by `seq(from, to, by)`. All items use the same `responseNames`. If you have some items with a different number of thresholds or different response names then you can call `responseCurve` for each item separately and `rbind` the results together.

**Usage**

```r
responseCurve(
  dl,  # a data list prepared by prepData
  fit,  # a stanfit object
  responseNames,  # a vector of labels for the possible responses
  item = dl$nameInfo$item,  # a vector of item names
  samples = 100,  # number of posterior samples
  from = qnorm(0.1),  # the starting latent difference value
  to = -from,  # the ending latent difference value
  by = 0.02  # the grid increment
)
```

**Arguments**

- `dl`: a data list prepared by `prepData`  
- `fit`: a `stanfit` object  
- `responseNames`: a vector of labels for the possible responses  
- `item`: a vector of item names  
- `samples`: number of posterior samples  
- `from`: the starting latent difference value  
- `to`: the ending latent difference value  
- `by`: the grid increment

**Value**

A data.frame with the following columns:

- `response`: Which response  
- `worthDiff`: Difference in worth  
- `item`: Which item  
- `sample`: Which sample  
- `prob`: Associated probability  
- `responseSample`: A grouping index for independent item response samples
roundRobinGraph

Response model

See cmp_probs for details.

See Also

Other data extractor: parDistributionCustom(), parInterval()

Examples

vignette('manual', 'pcFactorStan')

roundRobinGraph

Create an edge list with round-robin connectivity

Description

Create an edge list with round-robin connectivity

Usage

roundRobinGraph(name, N)

Arguments

name vector of vertex names
N number of comparisons

Value

An undirected graph represented as a data frame with each row describing an edge.

See Also

Other graph generators: twoLevelGraph()

Examples

roundRobinGraph(letters[1:5], 10)
Compute approximate leave-one-out (LOO) cross-validation for Bayesian models using Pareto smoothed importance sampling (PSIS).

You must use an `_ll` model variation (see `findModel`).

Usage

```r
toLoo(fit, ...)
```

Arguments

- `fit`: a `stanfit` object
- `...`: Additional options passed to `loo`.

Value

a loo object

See Also

`outlierTable`, `loo`

Examples

```r
palist <- letters[1:10]
df <- twoLevelGraph(palist, 300)
theta <- rnorm(length(palist))
names(theta) <- palist
df <- generateItem(df, theta, th=rep(0.5, 4))

df <- filterGraph(df)
df <- normalizeData(df)
dl <- prepCleanData(df)
dl$scale <- 1.5

m1 <- pcStan("unidim_ll", dl)

loo1 <- toLoo(m1, cores=1)
print(loo1)
```
twoLevelGraph

Create an edge list with a random two level connectivity

Description
Initially, edges are added from the first vertex to all the other vertices. Thereafter, the first vertex is drawn from a Beta(shape1, 1.0) distribution and the second vertex is drawn from a Beta(shape2, 1.0) distribution. The idea is that the edges will tend to connect a small subset of vertices from the top of the tree to leaf vertices. These vertex connections are similar to the pairs that you might observe in an elimination tournament. The selected vertices are sorted so it doesn’t matter whether shape1 > shape2 or shape1 < shape2.

Usage
twoLevelGraph(name, N, shape1 = 0.8, shape2 = 0.5)

Arguments
- name: vector of vertex names
- N: number of comparisons
- shape1: beta distribution parameter for first edge
- shape2: beta distribution parameter for second edge

Value
An undirected graph represented as a data frame with each row describing an edge.

See Also
Other graph generators: roundRobinGraph()

Examples
twoLevelGraph(letters[1:5], 20)

unfactor

Turn a factor back into a vector of integers

Description
Factors store values as integers and use a 'levels' attribute to map the integers to labels. This function removes the 'factor' class and levels attribute, leaving the vector of integers.

Usage
unfactor(f)
Arguments

- `f`: a factor

Examples

```r
f <- factor(letters[1:3])
print(f)
print(unfactor(f))
```

### withoutIndex

Remove the array indexing from a parameter name

**Usage**

```r
withoutIndex(name)
```

**Arguments**

- `name`: a parameter name

**Value**

the name without the square bracket parameter indexing

**Examples**

```r
withoutIndex(“foo[1,2]”)```
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