Package ‘multilevLCA’

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multilevLCA-package *Estimates and Plots Single-Level and Multilevel Latent Class Models*

Description

Efficiently estimates single- and multilevel latent class models with covariates, allowing for output visualization in all specifications. For more technical details, see Lyrvall et al (2023) <doi:10.48550/arXiv.2305.07276>.

Details

For estimating latent class models, see `multiLCA`.

For plotting latent class models, see `plot.multiLCA`

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References

Bakk, Z., & Kuha, J. (2018). Two-step estimation of models between latent classes and external variables. *Psychometrika, 83, 871-892*.

Bakk, Z., Di Mari, R., Oser, J., & Kuha, J. (2022). Two-stage multilevel latent class analysis with covariates in the presence of direct effects. *Structural Equation Modeling: A Multidisciplinary Journal, 29(2), 267-277*.

Di Mari, Bakk, Z., R., Oser, J., & Kuha, J. (2023). A two-step estimator for multilevel latent class analysis with covariates. Psychometrika.

Lukociene, O., Varriale, R., & Vermunt, J. K. (2010). The simultaneous decision(s) about the number of lower-and higher-level classes in multilevel latent class analysis. Sociological Methodology, 40(1), 247-283.

Examples

```
data = dataIEA
Y = colnames(dataIEA)[4+1:12]

out = multiLCA(data = data, Y = Y, iT = 2)
out
plot(out, horiz = FALSE)
```

`dataIEA` *Data for understanding of good citizenship behaviour*

Description

Data set from the International Civic and Citizenship Education Study 2016 (Schulz et al., 2018). As part of a comprehensive evaluation of education systems, the IEA conducted surveys in 1999, 2009 and 2016 in school classes of 14-year olds to investigate civic education with the same scientific rigor as the evaluation of more traditional educational skills of language and mathematics. The present study focuses on the third wave of the survey that was conducted in 2016.

Questions regarding citizenship norms in all three waves asked respondents to explain their understanding of what a good adult citizen is or does. The survey then lists a variety of activities for respondents to rate in terms of how important these activities are in order to be considered a good adult citizen. The twelve items range from obeying the law and voting in elections, to protecting the environment and defending human rights.

Covariates included are customary determinants of citizenship norms from the literature at the individual-level of socio-economic measures and country-level measure of gross domestic product (GDP) per capita.

Usage

```
data("dataIEA")
```

Format

A data frame with 90221 observations on the following 28 variables.

`ICCS_year` Year of survey

`COUNTRY` Country

`IDSTUD` Study ID

`TOTWGTS` Study weight

`obey` Always obeying the law

`rights` Taking part in activities promoting human rights

`local` Participating in activities to benefit people in the local community

`work` Working hard

`envir` Taking part in activities to protect the environment

`vote` Voting in every national election

`history` Learning about the country’s history

`respect` Showing respect for government representatives

`news` Following political issues in the newspaper, on the radio, on TV, or on the Internet

`protest` Participating in peaceful protests against laws believed to be unjust

`discuss` Engaging in political discussions `party` Joining a political party

`female` Female

`books` Number of books at home

`edexp` Educational expectations

`ed_mom` Mother education

`ed_dad` Father education

`nonnat_born` Non-native born

`immigrantfam` Immigrant family

`nonnat_lang` Non-native language level

`gdp_constant` GDP

`log_gdp_constant` Log GDP

`gdp_currentusd` GDP in USD

`log_gdp_currentusd` Log GDP in USD

References

Schulz, W., Ainley, J., Fraillon, J., Losito, B., Agrusti, G., & Friedman, T. (2018). Becoming citizens in a changing world: IEA International Civic and Citizenship Education Study 2016 international report. Springer.

`dataTOY` *Artificial data set*

Description

Artificial multilevel data set.

Usage

```
data("dataTOY")
```

Format

A data frame with 3000 observations on the following 13 variables.

`id_high` High-level id

`Y_1` Indicator n.1

`Y_2` Indicator n.2

`Y_3` Indicator n.3

`Y_4` Indicator n.4

`Y_5` Indicator n.5

`Y_6` Indicator n.6

`Y_7` Indicator n.7

`Y_8` Indicator n.8

`Y_9` Indicator n.9

`Y_10` Indicator n.10

`Z_low` Continuous low-level covariate

`Z_high` Continuous high-level covariate

References

Di Mari, Bakk, Z., R., Oser, J., & Kuha, J. (2023). A two-step estimator for multilevel latent class analysis with covariates. Under review. Available from https://arxiv.org/abs/2303.06091.

`multiLCA` *Estimates and plots single- and multilevel latent class models*

Description

The `multiLCA` function in the `multilevLCA` package estimates single- and multilevel measurement and structural latent class models. Moreover, the function performs two different strategies for model selection. Methodological details can be found in Bakk et al. (2022), Bakk and Kuha (2018), and Di Mari et al. (2023).

Different output visualization tools are available for all model specifications. See, e.g., `plot.multiLCA`.

Usage

```
multiLCA(
data,
Y,
iT,
id_high = NULL,
iM = NULL,
Z = NULL,
Zh = NULL,
incomplete = FALSE,
fixedslopes = FALSE,
startval = NULL,
kmea = TRUE,
extout = FALSE,
dataout = TRUE,
sequential = TRUE,
numFreeCores = 2,
maxIter = 1e3,
tol = 1e-8,
reord = TRUE,
fixedpars = 1,
```

```
NRmaxit = 100,
NRtol = 1e-6,
verbose = TRUE
)
```

Arguments

`data`	Input matrix or dataframe.
`Y`	Names of `data` columns with indicators.
`iT`	Number of lower-level latent classes.
`id_high`	Name of `data` column with higher-level id. Default: `NULL`.
`iM`	Number of higher-level latent classes. Default: `NULL`.
`Z`	Names of `data` columns with lower-level covariates (non-numeric covariates are treated as nominal). Default: `NULL`.
`Zh`	Names of `data` columns with higher-level covariates (non-numeric covariates are treated as nominal). Default: `NULL`.
`incomplete`	Whether to estimate the model with missing values included by means of full-information maximum-likelihood estimation (`TRUE`) or perform row-wise deletion of missing values (`FALSE`). Default: `FALSE`.
`fixedslopes`	Whether to estimate multilevel models with covariates with fixed lower-level slope parameters across the higher-level classes by means of log-linear parametrization. Default: `FALSE`.
`startval`	Name of `data` column with starting values for lower-level latent classes. Default: `NULL`.
`kmea`	Whether to compute starting values for single-level model using K-means (`TRUE`), which is recommended for algorithmic stability, or K-modes (`FALSE`). Default: `TRUE`.
`extout`	Whether to output extensive model and estimation information. Default: `FALSE`.
`dataout`	Whether to match class predictions to the observed data. Default: `TRUE`.
`sequential`	Whether to perform sequential model selection (`TRUE`) or parallelized model selection (`FALSE`). Default: `TRUE`.
`numFreeCores`	If performing parallelized model selection, the number of CPU cores to keep free. Default: `2`.
`maxIter`	Maximum number of iterations for EM algorithm. Default: `1e3`.
`tol`	Tolerance for EM algorithm. Default: `1e-8`.
`reord`	Whether to (re)order classes in decreasing order according to probability of scoring yes on all items. Default: `TRUE`.
`fixedpars`	One-step estimator (`0`), two-step estimator (`1`) or two-stage estimator (`2`). Default: `1`.
`NRmaxit`	Maximum number of iterations for Newton-Raphson algorithm. Default: `100`.
`NRtol`	Tolerance for Newton-Raphson algorithm. Default: `1e-6`.
`verbose`	Whether to print estimation progress. Default: `TRUE`.

Details

The indicator columns may be coded as as consecutive sequence of integers from 0, or as characters.

To directly estimate a latent class model, `iT` and (optionally) `iM` should be specified as a single positive integer. To perform model selection over range of consecutive positive integers as the number of latent classes, `iT` and/or `iM` may be specified in the form `iT_min:iT_max` and/or `iM_min:iM_max`. It is possible to specify `iT = iT_min:iT_max` with either `iM = NULL` or `iM` equal to a single positive integer, `iM = iM_min:iM_max` with `iT` equal to a single positive integer, or `iT = iT_min:iT_max` with `iM = iM_min:iM_max`. All model selection procedures return the output of the optimal model based on the BIC.

In the case where both `iT` and `iM` are defined as a range of consecutive positive integers, model selection can be performed using the sequential three-stage approach (Lukociene et al., 2010) or a simultaneous approach. The sequential approach involves (first step) estimating `iT_min:iT_max` single-level models and identifying the optimal alternative `iT_opt1` based on the BIC, (second step) estimating `iM_min:iM_max|iT = iT_opt1` multilevel models and identifying the optimal alternative `iM_opt2` based on the higher-level BIC, and (third step) estimating `iT_min:iT_max|iM = iM_opt2` multilevel models and identifying the optimal alternative `iT_opt3` based on the lower-level BIC. The simultaneous approach involves devoting multiple CPU cores on the local machine to estimate all combinations in `iT = iT_min:iT_max, iM = iM_min:iM_max` and identifying the optimal alternative based on the lower-level BIC.

Value

Single-level model estimation returns (if `extout = FALSE`, a subset):

`vPi` Class proportions

`mPhi` Response probabilities given the latent classes

`mU` Matrix of posterior class assignment (proportional assignment)

`mU_modal` Matrix of posterior class assignment (modal assignment)

`vU_modal` Vector of posterior class assignment (modal assignment)

`mClassErr` Expected number of classification errors

`mClassErrProb` Expected proportion of classification errors

`AvgClassErrProb` Average of `mClassErrProb`

`R2entr` Entropy-based R^2

`BIC` Bayesian Information Criterion (BIC)

`AIC` Akaike Information Criterion (AIC)

`vGamma` Intercepts in logistic parametrization for class proportions

`mBeta` Intercepts in logistic parametrization for response probabilities

`parvec` Vector of logistic parameters

`SEs` Standard errors

`Varmat` Variance-covariance matrix

`iter` Number of iterations for EM algorithm

eps	Difference between last two elements of log-likelihood sequence for EM algorithm
LLKSeries	Full log-likelihood series for EM algorithm
mScore	Contributions to log-likelihood score
spec	Model specification
missing_values	Strategy for handling of eventual missing values
sample_size	Final sample size for model estimation

Single-level model estimation with covariates returns (if extout = FALSE, a subset):

mPi	Class proportions given the covariates
vPi_avg	Sample average of mPi
mPhi	Response probabilities given the latent classes
mU	Matrix of posterior class assignment (proportional assignment)
mClassErr	Expected number of classification errors
mClassErrProb	Expected proportion of classification errors
AvgClassErrProb	Average of mClassErrProb
R2entr	Entropy-based R^2
BIC	Bayesian Information Criterion (BIC)
AIC	Akaike Information Criterion (AIC)
mGamma	Intercept and slope parameters in logistic models for conditional class membership
mBeta	Intercepts in logistic parametrization for response probabilities
parvec	Vector of logistic parameters
SEs_unc	Uncorrected standard errors
SEs_cor	Corrected standard errors (see Bakk & Kuha, 2018; Di Mari et al., 2023)
SEs_cor_gamma	Corrected standard errors only for the gammas (see Bakk & Kuha, 2018; Di Mari et al., 2023)
mQ	Cross-derivatives for asymptotic standard error correction in two-step estimation (see Bakk & Kuha, 2018; Di Mari et al., 2023)
Varmat_unc	Uncorrected variance-covariance matrix
Varmat_cor	Corrected variance-covariance matrix (see Bakk & Kuha, 2018; Di Mari et al., 2023)
mV2	Inverse of information matrix for structural model
iter	Number of iterations for EM algorithm
eps	Difference between last two elements of log-likelihood sequence for EM algorithm
LLKSeries	Full log-likelihood series for EM algorithm
spec	Model specification

`estimator`	Estimation approach for structural model
`missing_values`	Strategy for handling of eventual missing values
`sample_size`	Final sample size for model estimation

Multilevel model estimation returns (if `extout = FALSE`, a subset):

`vOmega`	Higher-level class proportions
`mPi`	Lower-level class proportions given the higher-level latent classes
`mPhi`	Response probabilities given the lower-level latent classes
`cPMX`	Posterior joint class assignment (proportional assignment)
`cLogPMX`	Log of `cPMX`
`cPX`	Posterior lower-level class assignment given high-level class membership (proportional assignment)
`cLogPX`	Log of `cPX`
`mSumPX`	Posterior higher-level class assignment for lower-level units after marginalization over the lower-level classes (proportional assignment)
`mPW`	Posterior higher-level class assignment for higher-level units (proportional assignment)
`mlogPW`	Log of `mPW`
`mPW_N`	Posterior higher-level class assignment for lower-level units (proportional assignment)
`mPMsumX`	Posterior lower-level class assignment for lower-level units after marginalization over the higher-level classes (proportional assignment)
`R2entr_low`	Lower-level entropy-based R^2
`R2entr_high`	Higher-level entropy-based R^2
`BIClow`	Lower-level Bayesian Information Criterion (BIC)
`BIChigh`	Higher-level Bayesian Information Criterion (BIC)
`ICL_BIClow`	Lower-level BIC-type approximation the integrated complete likelihood
`ICL_BIChigh`	Higher-level BIC-type approximation the integrated complete likelihood
`AIC`	Akaike Information Criterion (AIC)
`vAlpha`	Intercepts in logistic parametrization for higher-level class proportions
`mGamma`	Intercepts in logistic parametrization for conditional lower-level class proportions
`mBeta`	Intercepts in logistic parametrization for response probabilities
`parvec`	Vector of logistic parameters
`SEs`	Standard errors
`Varmat`	Variance-covariance matrix
`Infomat`	Expected information matrix
`iter`	Number of iterations for EM algorithm
`eps`	Difference between last two elements of log-likelihood sequence for EM algorithm

LLKSeries	Full log-likelihood series for EM algorithm
vLLK	Current log-likelihood for higher-level units
mScore	Contributions to log-likelihood score
spec	Model specification
missing_values	Strategy for handling of eventual missing values
sample_size	Final sample size for model estimation

Multilevel model estimation with lower-level covariates returns (if extout = FALSE, a subset):

vOmega	Higher-level class proportions
mPi	Lower-level class proportions given the higher-level latent classes and the covariates
mPi_avg	Sample average of mPi
mPhi	Response probabilities given the lower-level latent classes
cPMX	Posterior joint class assignment (proportional assignment)
cLogPMX	Log of cPMX
cPX	Posterior lower-level class assignment given high-level class membership (proportional assignment)
cLogPX	Log of cPX
mSumPX	Posterior higher-level class assignment for lower-level units after marginalization over the lower-level classes (proportional assignment)
mPW	Posterior higher-level class assignment for higher-level units (proportional assignment)
mlogPW	Log of mPW
mPW_N	Posterior higher-level class assignment for lower-level units (proportional assignment)
mPMsumX	Posterior lower-level class assignment for lower-level units after marginalization over the higher-level classes (proportional assignment)
R2entr_low	Lower-level entropy-based R^2
R2entr_high	Higher-level entropy-based R^2
BIClow	Lower-level Bayesian Information Criterion (BIC)
BIChigh	Higher-level Bayesian Information Criterion (BIC)
ICL_BIClow	Lower-level BIC-type approximation the integrated complete likelihood
ICL_BIChigh	Higher-level BIC-type approximation the integrated complete likelihood
AIC	Akaike Information Criterion (AIC)
vAlpha	Intercepts in logistic parametrization for higher-level class proportions
cGamma	Intercept and slope parameters in logistic models for conditional lower-level class membership
mBeta	Intercepts in logistic parametrization for response probabilities
parvec	Vector of logistic parameters

`SEs_unc`	Uncorrected standard errors
`SEs_cor`	Corrected standard errors (see Bakk & Kuha, 2018; Di Mari et al., 2023)
`SEs_cor_gamma`	Corrected standard errors only for the gammas (see Bakk & Kuha, 2018; Di Mari et al., 2023)
`mQ`	Cross-derivatives for asymptotic standard error correction in two-step estimation (see Bakk & Kuha, 2018; Di Mari et al., 2023)
`Varmat_unc`	Uncorrected variance-covariance matrix
`Varmat_cor`	Corrected variance-covariance matrix (see Bakk & Kuha, 2018; Di Mari et al., 2023)
`Infomat`	Expected information matrix
`cGamma_Info`	Expected information matrix only for the gammas
`mV2`	Inverse of information matrix for structural model
`iter`	Number of iterations for EM algorithm
`eps`	Difference between last two elements of log-likelihood sequence for EM algorithm
`LLKSeries`	Full log-likelihood series for EM algorithm
`vLLK`	Current log-likelihood for higher-level units
`mScore`	Contributions to log-likelihood score
`mGamma_Score`	Contributions to log-likelihood score only for the gammas
`spec`	Model specification
`estimator`	Estimation approach for structural model
`missing_values`	Strategy for handling of eventual missing values
`sample_size`	Final sample size for model estimation

Multilevel model estimation with lower- and higher-level covariates returns (if `extout = FALSE`, a subset):

`mOmega`	Higher-level class proportions given the covariates
`vOmega_avg`	Higher-level class proportions averaged over higher-level units
`mPi`	Lower-level class proportions given the higher-level latent classes and the covariates
`mPi_avg`	Sample average of `mPi`
`mPhi`	Response probabilities given the lower-level latent classes
`cPMX`	Posterior joint class assignment (proportional assignment)
`cLogPMX`	Log of `cPMX`
`cPX`	Posterior lower-level class assignment given high-level class membership (proportional assignment)
`cLogPX`	Log of `cPX`
`mSumPX`	Posterior higher-level class assignment for lower-level units after marginalization over the lower-level classes (proportional assignment)

mPW	Posterior higher-level class assignment for higher-level units (proportional assignment)
mlogPW	Log of mPW
mPW_N	Posterior higher-level class assignment for lower-level units (proportional assignment)
mPMsumX	Posterior lower-level class assignment for lower-level units after marginalization over the higher-level classes (proportional assignment)
R2entr_low	Lower-level entropy-based R^2
R2entr_high	Higher-level entropy-based R^2
BIClow	Lower-level Bayesian Information Criterion (BIC)
BIChigh	Higher-level Bayesian Information Criterion (BIC)
ICL_BIClow	Lower-level BIC-type approximation the integrated complete likelihood
ICL_BIChigh	Higher-level BIC-type approximation the integrated complete likelihood
AIC	Akaike Information Criterion (AIC)
mAlpha	Intercept and slope parameters in logistic models for conditional higher-level class membership
cGamma	Intercept and slope parameters in logistic models for conditional lower-level class membership
mBeta	Intercepts in logistic parametrization for response probabilities
parvec	Vector of logistic parameters
SEs_unc	Uncorrected standard errors
SEs_cor	Corrected standard errors (see Bakk & Kuha, 2018; Di Mari et al., 2023)
SEs_cor_alpha	Corrected standard errors only for the alphas (see Bakk & Kuha, 2018; Di Mari et al., 2023)
SEs_cor_gamma	Corrected standard errors only for the gammas (see Bakk & Kuha, 2018; Di Mari et al., 2023)
mQ	Cross-derivatives for asymptotic standard error correction in two-step estimation (see Bakk & Kuha, 2018; Di Mari et al., 2023)
Varmat_unc	Uncorrected variance-covariance matrix
Varmat_cor	Corrected variance-covariance matrix (see Bakk & Kuha, 2018; Di Mari et al., 2023)
Infomat	Expected information matrix
cAlpha_Info	Expected information matrix only for the alphas
cGamma_Info	Expected information matrix only for the gammas
mV2	Inverse of information matrix for structural model
iter	Number of iterations for EM algorithm
eps	Difference between last two elements of log-likelihood sequence for EM algorithm
LLKSeries	Full log-likelihood series for EM algorithm
vLLK	Current log-likelihood for higher-level units

mScore	Contributions to log-likelihood score
mAlpha_Score	Contributions to log-likelihood score only for the alphas
mGamma_Score	Contributions to log-likelihood score only for the gammas
spec	Model specification
estimator	Estimation approach for structural model
missing_values	Strategy for handling of eventual missing values
sample_size	Final sample size for model estimation

References

Bakk, Z., & Kuha, J. (2018). Two-step estimation of models between latent classes and external variables. *Psychometrika, 83, 871-892*.

Bakk, Z., Di Mari, R., Oser, J., & Kuha, J. (2022). Two-stage multilevel latent class analysis with covariates in the presence of direct effects. *Structural Equation Modeling: A Multidisciplinary Journal, 29(2), 267-277*.

Di Mari, Bakk, Z., R., Oser, J., & Kuha, J. (2023). A two-step estimator for multilevel latent class analysis with covariates. Psychometrika.

Lukociene, O., Varriale, R., & Vermunt, J. K. (2010). The simultaneous decision(s) about the number of lower-and higher-level classes in multilevel latent class analysis. Sociological Methodology, 40(1), 247-283.

Examples

```
# Use the artificial data set
data = dataTOY

# Define vector with names of columns with items
Y = colnames(data)[1+1:10]

# Define name of column with higher-level id
id_high = "id_high"

# Define vector with names of columns with lower-level covariates
Z = c("Z_low")

# Define vector with names of columns with higher-level covariates
Zh = c("Z_high")

# Single-level 3-class LC model with covariates
out = multiLCA(data, Y, 3, Z = Z, verbose = FALSE)
out

# Multilevel LC model
out = multiLCA(data, Y, 3, id_high, 2, verbose = FALSE)
out

# Multilevel LC model lower-level covariates
out = multiLCA(data, Y, 3, id_high, 2, Z, verbose = FALSE)
```

```
out

# Multilevel LC model lower- and higher-level covariates
out = multiLCA(data, Y, 3, id_high, 2, Z, Zh, verbose = FALSE)
out

# Model selection over single-level models with 1-3 classes
out = multiLCA(data, Y, 1:3, verbose = FALSE)
out

# Model selection over multilevel models with 1-3 lower-level classes and
# 2 higher-level classes
out = multiLCA(data, Y, 1:3, id_high, 2, verbose = FALSE)
out

# Model selection over multilevel models with 3 lower-level classes and
# 1-2 higher-level classes
out = multiLCA(data, Y, 3, id_high, 1:2, verbose = FALSE)
out

# Model selection over multilevel models with 1-3 lower-level classes and
# 1-2 higher-level classes using the default sequential approach
out = multiLCA(data, Y, 1:3, id_high, 1:2, verbose = FALSE)
out
```

`plot.multiLCA` *Plots conditional response probabilities*

Description

Visualizes conditional response probabilities estimated by the `multiLCA` function. The method works for both single- and multilevel models.

Let `out` denote the list object returned by the `multiLCA` function. Executing `plot(out)` visualizes the conditional response probabilities given by the `mPhi` matrix in `out`.

Usage

```
## S3 method for class 'multiLCA'
plot(x, horiz = FALSE, clab = NULL, ...)
```

Arguments

`x`	The object returned by the `multiLCA` function
`horiz`	Whether item labels should be oriented horizontally (`TRUE`) or vertically (`FALSE`). Default `FALSE`
`clab`	A character vector with user-specified class labels, if available, in the order "Class 1", "Class 2", ... under the default settings, i.e. top-to-bottom. Default `NULL`
`...`	Additional plotting arguments

Value

No return value

Examples

```
# Use IEA data
data = dataIEA

# Define vector with names of columns with items
Y = colnames(data)[4+1:12]

# Define number of (low-level) classes
iT = 3

# Estimate single-level measurement model
out = multiLCA(data = data, Y = Y, iT = iT)
out

# Plot conditional response probabilities with default settings
plot(out)

# Plot with vertical item labels and custom class labels
plot(out, horiz = FALSE, clab = c("Maximal", "Engaged", "Subject"))
```

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