

Package ‘multilevLCA’

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Title 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) <[arXiv:2305.07276](https://arxiv.org/abs/2305.07276)>.

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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) <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	<i>Artificial data set</i>
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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,  
  extout = FALSE,  
  dataout = TRUE,  
  kmea = TRUE,  
  sequential = TRUE,  
  numFreeCores = 2,  
  maxIter = 1e3,  
  tol = 1e-8,  
  reord = TRUE,  
  fixedpars = 1,  
  NRmaxit = 100,  
  NRtol = 1e-6,  
  verbose = TRUE  
)
```

Arguments

<code>data</code>	Input matrix or dataframe.
<code>Y</code>	Names of data columns with indicators.
<code>iT</code>	Number of lower-level latent classes.
<code>id_high</code>	Name of data column with higher-level id. Default: NULL.
<code>iM</code>	Number of higher-level latent classes. Default: NULL.
<code>Z</code>	Names of data columns with lower-level covariates (non-numeric covariates are treated as nominal). Default: NULL.
<code>Zh</code>	Names of data columns with higher-level covariates (non-numeric covariates are treated as nominal). Default NULL
<code>extout</code>	Whether to output extensive model and estimation information. Default: FALSE.
<code>dataout</code>	Whether to match class predictions to the observed data. Default: TRUE.
<code>kmea</code>	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.
<code>sequential</code>	Whether to perform sequential model selection (TRUE) or parallelized model selection (FALSE). Default: TRUE.
<code>numFreeCores</code>	If performing parallelized model selection, the number of CPU cores to keep free. Default: 2.
<code>maxIter</code>	Maximum number of iterations for EM algorithm. Default: 1e3.
<code>tol</code>	Tolerance for EM algorithm. Default: 1e-8.
<code>reord</code>	Whether to (re)order classes in decreasing order according to probability of scoring yes on all items. Default: TRUE.
<code>fixedpars</code>	One-step estimator (0), two-step estimator (1) or two-stage estimator (2). Default: 1.
<code>NRmaxit</code>	Maximum number of iterations for Newton-Raphson algorithm. Default: 100.
<code>NRtol</code>	Tolerance for Newton-Raphson algorithm. Default: 1e-6.
<code>verbose</code>	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 = TRUE`, a subset):

<code>vPi</code>	Class proportions
<code>mPhi</code>	Response probabilities given the latent classes
<code>mU</code>	Matrix of posterior class assignment (proportional assignment)
<code>mU_modal</code>	Matrix of posterior class assignment (modal assignment)
<code>vU_modal</code>	Vector of posterior class assignment (modal assignment)
<code>mClassErr</code>	Expected number of classification errors
<code>mClassErrProb</code>	Expected proportion of classification errors
<code>AvgClassErrProb</code>	Average of <code>mClassErrProb</code>
<code>R2entr</code>	Entropy-based R^2
<code>BIC</code>	Bayesian Information Criterion (BIC)
<code>AIC</code>	Akaike Information Criterion (AIC)
<code>vGamma</code>	Intercepts in logistic parametrization for class proportions
<code>mBeta</code>	Intercepts in logistic parametrization for response probabilities
<code>parvec</code>	Vector of logistic parameters
<code>SEs</code>	Standard errors
<code>Varmat</code>	Variance-covariance matrix
<code>iter</code>	Number of iterations for EM algorithm
<code>eps</code>	Difference between last two elements of log-likelihood sequence for EM algorithm
<code>LLKSeries</code>	Full log-likelihood series for EM algorithm
<code>mScore</code>	Contributions to log-likelihood score
<code>spec</code>	Model specification

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

<code>mPi</code>	Class proportions given the covariates
<code>vPi_avg</code>	Sample average of <code>mPi</code>
<code>mPhi</code>	Response probabilities given the latent classes
<code>mU</code>	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)
cGamma	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
SEs_cor_gamma	Corrected standard errors only for the gammas
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
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

Multilevel model estimation returns (if extout = TRUE, 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

Multilevel model estimation with lower-level covariates returns (if extout = TRUE, 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
SEs_cor_gamma	Corrected standard errors only for the gammas
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
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

Multilevel model estimation with lower- and higher-level covariates returns (if `extout = TRUE`, 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
SEs_cor_alpha	Corrected standard errors only for the alphas
SEs_cor_gamma	Corrected standard errors only for the gammas
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
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

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 <code>multiLCA</code> 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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